This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101070046

D2.1 Requirements and human-centric recommendations

Deliverable No.	D2.1	**Due Date**	06/October/2023
Description	Report that includes the stakeholders' expectations for the ALCHIMIA project and insights and foresight recommendations for human-centric technology development and insertion.		
Type	Report	**Dissemination Level**	PU
Work Package No.	WP2	**Work Package Title**	Human-centric design
Version	1.0	**Status**	Final

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History

Date	Version	Change	Initials of Authors
25/06/2023	0.1	Initial Document Outline	MW
03/08/2023	0.2	Revised Document Outline	MW
08/08/2023	0.3	Initial draft	MW, RH, DS, VDI, JRC
22/09/2023	0.4	Review with partners	MW, RH, DS, VDI, JRC, ECT
04/10/2023	0.5	Final review and editing	DS, GB, MW
05/10/2023	0.6	Final Revision	DS, DE, MW, RH
06/10/2023	1.0	Final version for submission	DE

Key data

Lead Editor	Cardiff University
Internal Reviewer(s)	Fonderia di Torbole (FdT)

Abstract

This report constitutes *Deliverable 2.1: Requirements and human-centric recommendations* of the ALCHIMIA project. ALCHIMIA is a tool that will help companies in the steel and metal sector to continuously optimise production process by exploiting a broad range of production-related data. The ALCHIMIA project adopts a human-centred approach to design that guides the design and development process in specific ways to ensure the views, interests and needs of users and stakeholders are taken during the design phase of the technology.

The report provides an overview and summary of activities conducted and findings obtained during the initial stages of the development of the AI-based ALCHIMIA system. It starts by providing an overview of current production processes in two participating companies, one an EAF-based steel producer and the other a manufacturer of disk brakes for the automotive industry (Part 2: Setting the Scene). The description of current approaches leads to a description of efficiency problems in both industrial settings that ALCHIMIA is aiming to solve (Part 3: ALCHIMIA and its Functions).

To effectively take user and stakeholder views, interests and needs into account, they need to be systematically elicited and ultimately translated into system requirements that constrain and guide the actual technical design of the ALCHIMIA system. Part 4 of the report (User and Stakeholder Requirements and Expectations) provides an overview of the requirement elicitation activities conducted as part of the ALCHIMIA project. Findings and outcomes of these activities are also presented.

In Part 5 (Human-Centred Design Recommendations), we reflexively analyse and evaluate the alignment of the design and development activities in the ALCHIMIA project with six human-centred design principles. While this evaluation indicates that the ALCHIMIA project is well aligned with the human-centred design principles, there are aspects that can be improved. We thus make three recommendations that, if implemented, should ensure improved alignment of the ALCHIMIA project with human-centred design prescriptions.

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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List of Abbreviations

AI HLEG	High-Level Expert Group on Artificial Intelligence
ALTAI	Assessment List for Trustworthy Artificial Intelligence
BF	Blast Furnace
CL	Continual Learning
EAF	Electric Arc Furnace
FL	Federated Learning
HCD	Human Centred Design

Executive Summary

This report constitutes *Deliverable 2.1: Requirements and human-centric recommendations* of the ALCHIMIA project. It provides an overview and summary of activities conducted and findings obtained during the initial stages of the development of the AI-based ALCHIMIA system. ALCHIMIA is a tool that will help companies in the steel and metal sector to continuously optimise production process by exploiting a broad range of production-related data. The ALCHIMIA project adopts a human-centred approach to design that guides the design and development process to ensure the views, interests and needs of users and stakeholders are included in the design phase of the technology.

The ALCHIMIA project involves an EAF-based steel producer and a manufacturer of disc brakes for the automotive industry. Current production processes in the EAF plants are still suboptimal in various ways: the classification and characterisation of scrap is relatively crude; steel recipes are based on past experience and incorporate relatively large safety margins; processes within EAFs are also relatively poorly understood, preventing more exact control of melting processes. ALCHIMIA aims to optimise aspects of these processes. The use of ALCHIMIA in the automotive plant is designed to overcome an inherent problem related to the production of cast iron car parts: some important quality checks can only be performed after a significant period of time passes, due to the need for products to have cooled sufficiently.

ALCHIMIA is aiming to solve these efficiency problems by leveraging data obtained at various stages of the production process by means of machine learning, or AI, incorporating federated and continual learning. The expectation is that ALCHIMIA can support EAF plants to optimise costs and resource use. In the automotive parts plant, the ALCHIMIA system is to be used in production to predict the quality of final products based on a range of data characterising material input and production processes.

A series of *User and Stakeholder Requirements and Expectations* were identified and this report provides an overview of the requirement elicitation activities conducted (i.e. use case forms, technical visits, social research) and the resultant system requirements that constrain and guide the actual technical design of the ALCHIMIA system. A total of 38 functional and 20 non-functional requirements were identified.

ALCHIMIA is to adopt a Human-Centred Design (HCD) and the sociological research, reported here, reflexively analyses and evaluates the alignment of the design and development activities in the ALCHIMIA project with six human-centred design (HCD) principles. While this evaluation indicates that the ALCHIMIA project is well aligned with the HCD principles, there are aspects that can be improved. Three recommendations are made that, if implemented, should ensure improved alignment of the ALCHIMIA project with HCD prescriptions:

(i) more structured, frequent and intense communication and collaboration between users, stakeholders and developers to prevent misunderstandings affecting the technological design;

(ii) more general information (and mechanisms for its delivery) for workers within plants, ensuring that workers (users) have clear and honest explanations as to why a new technology is needed and the likely consequences for the company and their jobs;

(iii) more interdisciplinary working between the social science and technical partners to ensure that a newly developed AI technology can work as intended and align with HCD principles.

1 Introduction

1.1 Purpose

This report constitutes the first of three deliverables related to Work Package 2 'Human-Centric Design' of the ALCHIMIA Project. According to the project proposal, 'ALCHIMIA aims to build a platform based on Federated Learning (FL) and Continual Learning (CL) to help big European metallurgy industries unlock the full potential of AI to support the needed transformations to create high-quality, competitive, efficient and green production processes. The project will address specifically the challenges of the steel sector, creating an innovative system that automates and optimises the production process dynamically with a holistic approach that includes scrap recycling and steelmaking. As its name suggests, ALCHIMIA will find an optimal mix to reduce energy consumption, emissions and waste generation of the steelmaking process, while also guaranteeing to obtain high-quality products. The replicability and scalability of ALCHIMIA will be enabled through the participation in the project of a complementary use case for the manufacturing of automotive parts.'

In this wider project context, Work Package 2 is paying attention to the 'social' aspects of the design and development of the ALCHIMIA system. This includes various processes to elicit views, preferences and requirements of users and stakeholders regarding the design and functionality of the system (How should it work? What should it be able to do?), ethical considerations (How much control to cede to technology? How to make the system robust and safe?) and potential consequences of using the technology (Does its use require new competences? Does its use contribute to job-losses or deskilling?).

The ALCHIMIA project proposal suggests that Deliverable D2.1 concentrates on user requirements and human-centric recommendations. Specifically, the Deliverable is described as follows:

D2.1 ***Requirements*** *and* ***human-centric recommendations:*** *This deliverable will include the* ***stakeholders' expectations****. Also, the findings of the research with survey results and interviews* ***provide insights and foresight recommendations for human-centric technology development and insertion.***[1]

1.2 Scope

The description suggests that the Deliverable should focus on two broad areas:

First, the user and stakeholder requirements and expectations are to be described. These have been identified through two separate processes: (1) a standardised use case definition process that mainly identified technical requirements and specifications from the perspective of users and stakeholders located within the respective companies that plan to use the ALCHIMIA system, and (2) a sociological research process using surveys and qualitative interviews involving prospective stakeholders and users in the respective companies participating in ALCHIMIA.

[1] ALCHIMIA Project Proposal, p. 35.

Second, recommendations are to be made to ensure that the design, development and insertion of the ALCHIMIA system is aligned with human-centred design principles. Human-centred design (HCD) is an approach to problem-solving, technological innovation and/or interactive system development that, while not new, has only recently risen to prominence. The basic tenet of this approach is that technologies or interactive systems become more acceptable, will be used more efficiently and effectively and have less adverse consequences when the requirements of users and stakeholders are continuously considered during development, implementation and use. In 2019, it became embedded in *ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems.*

1.3 Structure of Report

The report comprises four main parts. The first part sets the scene by describing the two different company settings with their respective production processes into which the ALCHIMIA system is to be inserted. One company is a foundry located in Italy that produces parts for the automotive sector. The modern production systems are largely optimised but there is still room for marginal efficiency gains due to the temporal lag between actual production of parts and the verification of the quality of these parts. Data-based production quality predictions can optimise production as suspected faulty product batches can be pulled earlier from production lines, thereby saving energy and costs. The other ALCHIMIA use case will be implemented in EAF steel plants in Spain, France and Poland, which all belong to the same holding company. While they largely operate with the same production systems, all three plants operate in very different contexts characterised by the availability of scrap, the costs of energy and demand for different products. The challenge these plants face is to utilise available production data to find the right balance between energy use, scrap metal use and product quality.

The second part builds on the first part and focuses on the anticipated functions for the ALCHIMIA system in the respective use contexts. Regarding functions, the two different use cases demonstrate that the same interactive AI system – ALCHIMIA – can support different functionalities in industrial contexts. In the case of the Italian foundry, ALCHIMIA is mainly fulfilling a 'predictive' function as the analysis of relevant production data is used to predict the final product quality much earlier than is currently possible. In the case of the EAF steel plants, in contrast, ALCHIMIA is fulfilling a 'prescriptive' function as it is supposed to intervene in the actual production processes to improve the efficiency of production processes.

The third part focuses on a variety of requirements that the ALCHIMIA system needs to fulfil or meet so that it does not only function in a narrow technical sense but also contributes to wider operational, organisational and societal goals such as reducing the environmental impact of metal production systems or reducing waste. The requirements analysis is thus a necessary step to ensure that ALCHIMIA both functions technically as intended while also fitting into particular social contexts. The requirements analysis has followed procedural guidance from ISO standard 29148-2011, which distinguishes a number of different, interrelated contexts that are linked to a variety of requirements defined by users and stakeholders that will to a significant extent determine the final design and functionality of the ALCHIMIA system. The requirements analysis performed as part of this project also included two additional elements not prescribed by the ISO standard: 1) an analysis of the alignment of the proposed system with a number of 'ethical requirements' that are designed to enhance the trustworthiness of the AI-based ALCHIMIA system has been conducted; 2) attention has also been paid to 'social requirements' which differ from technical requirements in the sense that they are directed towards social contexts. Social requirements set out to what extent and in which way social contexts have to change to allow a technical system like ALCHIMIA to fit into society.

The fourth part concentrates on aspects of the human-centred design (HCD) approach to which the ALCHIMIA project is committed. Guidance as to how to achieve human-centred design is provided by ISO standard ISO 9241-110. ALCHIMIA's alignment with and adherence to the six HCD principles is analysed and evaluated. Based on these activities, a number of recommendations are derived that, if implemented, should ensure improved and continued alignment of ALCHIMIA activities with the HCD approach.

2 Setting the Scene: The ALCHIMIA Use Cases

2.1 EAF Steelmaking

The CELSA Group consists of six business groups. It has 120 work sites, 7 steel mills, 12 rolling mills and 45 recycling plants, across France, Spain, Poland, Norway, Denmark, Finland, UK and Ireland. Three melt shops of the CELSA Group will host the ALCHIMIA pilot. They are located in France (Bayonne), Spain (Barcelona) and Poland (Ostrowiec Świętokrzyski). The melt shops in Spain and Poland produce steel for use in the construction industry and Celsa France's steel is used in the automotive industry. Each of these three plants has approximately 450 employees. Production workers are organised in polyvalent teams.

Steel is made via two routes: Blast Furnace (BF) – 60% of total production - and Electric Arc Furnace (EAF). While BF is used to create new or 'virgin' steel from iron, EAF produces steel from scrap metal, usually collected for recycling.

The basic elements of the EAF steel making process encompass a number of steps from scrap purchasing to checking the final product quality. Four broad stages are of interest in the context of the ALCHIMIA project.

Table 1: EAF Steelmaking Process

STAGE	DESCRIPTION
Scrap Purchasing	Scrap buyers working for the company buy scrap metal on regional, national and international scrap metal markets. Scrap metal markets tend to be sellers' markets but long-term relationships with scrap dealers and/or vertical integration of scrap sellers within EAF companies can moderate sellers' powers. The market conditions mean that scrap purchasing cannot be standardised or structured according to the steel-making company's preferences, as such an approach would adversely affect prices from the purchaser's point of view. Rather, retaining flexibility with regard to what is purchased and avoiding situations where particular scrap grades are urgently needed is important from the steel-makers' point of view. The quality of scrap metal is determined by certain characteristics of the scrap (density, purity, size), which also underpin national, European and global scrap classifications that differentiate a variety of scrap grades.[2]

[2] Due to the importance of transport costs, steel purchasing tends to be focused on regional or national scrap markets. Hence, companies tend to use mainly scrap classifications used within the country they are located in. International scrap purchasing does happen, however. While national scrap classifications tend to vary slightly from country to country, they are relatable and translatable into scrap classifications used in global scrap markets.

STAGE	DESCRIPTION
Scrap Processing	Once scrap metal is bought, it will eventually be delivered to the scrap yard of the EAF plants. The processing of scrap varies from plant to plant due to different local arrangements and conditions. For example, vertical integration of scrap sellers into the larger company in Poland means that scrap delivered by sellers belonging to the company will not be checked further upon arrival, while all deliveries by non-company scrap sellers will be checked in some detail. For this purpose, trucks are unloading the scrap near the designated scrap storage space and a scrap sorter visually inspects the unloaded scrap from close distance to determine to which degree the actual scrap aligns with what has been ordered, as well the level of impurities. Scrap sorters file detailed reports about each delivery that includes photos and descriptions of the condition and quality of the delivered scrap. In France, in contrast, superficial camera-based inspection of scrap upon arrival is all that is possible due to limited space within the plant and the high volume of deliveries. Trucks are directly unloading scrap into the scrap storage area, which makes retrospective checking redundant. Scrap delivered by ship – the convenient coast-based location makes this possible – is also directly unloaded into the main open-air scrap storage area without any further detailed checks. In Spain, an AI-based system (I-Scrap) is currently being tested to automate scrap identification. For this purpose, all trucks unload their scrap in dedicated and marked bays that are surveyed by a range of cameras linked to the I-Scrap system. The cameras support a multi-spectral analysis of the scrap that eventually ought to lead to a very accurate classification of the scrap and impurities. Apart from identifying delivered scrap (i.e. the process of checking whether delivered scrap is matching specifications on purchasing orders), cleaning and milling (only partially applied) and storing scrap in dedicated areas according to the internally applied organisation are other significant processes at this stage. Processing scrap before storing it – cleaning and milling it – is relatively costly but can improve steel quality and it is down to operational considerations and calculations as to what amount of scrap is processes before storage. Scrap yard organisation, which determines how and where scrap is stored, has a direct impact on steel production. First, the organisation of scrap has affordances for the kind of steel recipes that can be used in the company. The more granular the internal classification and separation of scrap, the more flexibility with regard to recipe selection. Second, clarity with regard to what grade of scrap is stored is important for basket charging (next step, see below) as this will impact the accuracy of what is loaded into baskets. Third, whether scrap is stored in the open or under roofs can impact recipe selection, as openly stored scrap is difficult or impossible to use for production purposes during rainy periods. Fourth, the cleanliness and purity of scrap has impact on energy use and steel quality. Fifth, the size of scrap parts can affect the loading of baskets. Bigger pieces might lead to overfilling of baskets (which leads to extra energy use as lids on

STAGE	DESCRIPTION
	furnaces will not immediately close) or might necessitate the use of additional baskets to produce a full batch).
Charging Baskets	Within the company, EAF steel is produced for continuous casting in batches of about 130t to 150t. A single EAF basket – the vessel in which scrap metal is turned into liquid steel – can take up to around 80t of steel scrap. This means that a batch of steel is produced by charging at least 2 baskets to reach the desired amount. In 'normal' circumstances, a full heat, i.e. a batch, will be produced by charging three baskets.[3] In some cases, for example if only very low quality scrap (which tends to have very low density) is available, producing a steel batch might require up to 5 baskets, which also means that a lot more energy has to be expended compared to a batch produced with 2 or 3 baskets. Baskets are charged according to recipes that specify what kind, how much and in what order particular grades of scrap metals are to be loaded into baskets. In two of the three plants under consideration (Poland and Spain), production managers were responsible for recipe selection while in the third plant (France), the scrap yard manager had responsibility for the selection of steel recipes. The recipes are informed by historic steel making data and are stored in an internal data base. While some recipes are used rarely or only occasionally, others tend to be reused hundreds of times. Which recipe is selected depends on a number of factors: current electricity costs, availability of certain scrap grades, desired steel grade to be produced according to customer requests as well as a number of other considerations (such as weather (e.g. some scrap grades might be wet and are therefore not used), desire to move or use particular scrap grades, (non-)availability of certain staff members). Recipes include sufficient margins of error which means that scrap charging of baskets currently requires only moderate accuracy. Nonetheless, in all plants, data about what is really put in the baskets (in contrast to what the recipes say) are generated and stored internally. In this context, the role of scrap crane operators is particular important as basket charging needs to follow a number of prescriptions to achieve optimal outcomes. Selecting the right kind of scrap, avoiding obvious impurities, the order of putting scrap into the basket and the placement of scrap within the basket are especially important factors that can have important effects on final product quality and production costs (via energy costs). Moreover, over-

[3] A typical basket charging pattern is 80t of scrap in the first basket, then 50t and then up to 10t.

STAGE	DESCRIPTION
	charging needs to be avoided as this will lead to a sub-optimal melting process due to an open lid on the furnace. The use of multiple baskets affords opportunities for corrections. While the first basket is usually charged to the maximum, subsequent baskets tend to be only partially filled and therefore afford room for adjustments.
EAF Furnace	Charged baskets are successively inserted into the EAF furnace where the scrap is melted with the help of a set of electrodes that are inserted into the basket. Large amounts of electric energy create an electric arc that is sufficiently hot to melt the scrap metal. Melting a full basket takes less than an hour. Once a charge has melted, the liquid steel is transferred into a ladle furnace, while the EAF furnace is charged with another basket. The melting process is largely driven by bespoke software, but operators retain some level of control as they intervene in the process in various ways (e.g., shut the process down in case of problems or end the melting process manually if they suspect the melting process has already been completed). Furnace operators are also responsible for adding a range of additives to the furnace. A range of furnace performance data is automatically obtained and inserted into local databases during the melting process.

The liquid steel is further processed in the three plants participating in the ALCHIMIA project, but these subsequent processes, starting with continuous casting, will not be impacted by the ALCHIMIA system and are therefore not further considered in this report.

Current production processes in the EAF plants are still suboptimal in various ways. The classification and characterisation of scrap is relatively crude, which makes it difficult to control exactly what is charged into baskets. Steel recipes are based on past experience and incorporate relatively large safety margins in terms of the quantity of ingredients to ensure desired outcome specifications are met under varying circumstances. Processes within EA furnaces are also relatively poorly understood, preventing more exact control of melting processes. By leveraging data obtained at various stages of the production process, the hope and expectation is that ALCHIMIA can help to optimise production processes in a way that optimises costs and resource use.

2.2 Automotive parts

FDT produces and sells brake discs and drums, castings and machined parts for the automotive sector, which involves utilising about 100.000 tons of cast iron per annum. FDT is one of the most modern foundries in the EU, holding a quality system assessed in compliance with the higher automotive market standards. Moreover, FDT belongs to the EF group holding other two separate foundries producing different products, namely Pilenga Baldassarre Foundry S.r.l., which treats Grey and nodular cast iron for several industrial sectors, and Fond-Stamp S.p.A., which focuses on the manufacturing of moulding dies for the automotive industry in cast iron and steel by lost foam polystyrene patterns. All the companies of the group develop rigorous monitoring and assessment of the environmental impact of their production cycles and are keen to continuously improving energy and resource efficiency together with product quality.

FDT uses as furnace a long campaign hot blasting cupola with a maximum capacity of 30 tons/h and two holding furnaces with 20 tons and 80 tons capacity respectively. Mobile ladles, moved by forklifts, are used to transfer liquid metal from the holding furnaces to two pouring furnaces, one for each moulding line. In case of high carbon production or special grey cast iron, there are two tandem electric induction furnaces. The production occurs on two horizontal moulding lines. Their brake disc production is mainly for cars (91%) and the rest is for commercial vehicles (9%). Of the total casting production (around 12 million pieces per year), forty percent are shipped raw and 60% are machined internally. Seventy percent are solid discs, 18% are vented discs and 12% are brake drums. FDT has approximately 450 employees. Production workers are organised in polyvalent teams.

The foundry manufacturing high quality car parts participating in the ALCHIMIA project is located in Northern Italy. Compared to EAF-based steel making, production processes are more intricate and complex. Eight different phases in the production process can be distinguished although their relevance for the purposes of the ALCHIMIA project vary.

Table 2: Automotive parts production process

STAGE	DESCRIPTION
Raw Material Acceptance	Given that highly standardised car parts are manufactured, raw material intake – mainly pig iron, high-quality scrap and a range of additives such as Castina and Ferro Alloys – is very stable. Raw materials are accounted for (i.e. measured), but chemical analysis on raw materials is only performed on samples after arrival at the plant. Suppliers are also regularly audited to ensure high standards are continuously applied. Internal data bases hold all the relevant data about raw materials used in the production processes. Available measurements of input data: inoculant quantity, measurement of chemical composition (%) of liquid metal, temperatures, thermal properties during casting (data available at the beginning of the process to set up the casting process. Data are checked on an hourly basis).
Cores	To accurately cast ventilated brake discs, the company has to produce high-quality cores that are then impressed into the mould to create an exactly specified cavity into which liquid cast iron can be poured. In a dedicated production area, these cores are manufactured on-site.
Moulding Sands	A type of sand-based moulding is used for the car part production. The moulds' preparation is meticulously quality checked to avoid any subsequent faults during production.
Melting	A cupola furnace is used to produce a steady supply of liquid metal with highly standardised characteristics during production periods which tend to last 5/6 days. The company obtains a range of automated and detailed measurements relating to temperature, energy use and ingredients in order to keep continuous metal production as stable and standardised

STAGE	DESCRIPTION
	as possible. The data is automatically inserted into the company's production software and data base. The liquid cast iron is transferred from the cupola furnace to two holding furnaces that subsequently supply mobile ladle furnaces which in turn are used for pouring liquid metal into the mould.
Pouring in Mould	The three previous preparatory stages culminate in the process that sees liquid metal being poured into the prepared moulds. Liquid metal is transferred from holding furnaces to smaller mobile ladle furnaces that have to be regularly refilled by operators using forklifts. During the pouring process, regular temperature checks are manually performed every half hour. The temperature readings are then manually inserted into a database by the ladle furnace operator. At the same time as the temperature readings, samples of the liquid metal are taken, and these samples are immediately transferred to the in-house laboratory where a range of chemical and physical tests are performed to ensure the liquid metal is aligned with certain quality parameters. The results of the chemical analysis and physical tests are automatically inserted into the company's production software and data base.
Hourly Control	The cooling process takes several hours and involves de-stacking, shakeout and shotblasting. Products not conforming with the required standards are either re-worked or discarded (i.e. they re-enter the production process in the form of scrap metal). An important part of this period are hourly controls of the finished products. This involves a range of lab-based tests that measure hardness, natural frequency, inner integrity, mechanical resistance and structural properties of the casts. Some of these tests, such as testing acoustic emissions (natural frequency), can only be meaningfully performed after a considerable amount of time has passed (about 3h). This means that if a fault is detected at this stage, the company will have continued to produce under potentially sub-optimal conditions for several hours, which, in the worst case, will result in a huge amount of wasted energy and a lot of scrap. All data are automatically recorded and integrated into the company's data base.
Final Check	The final product check ensures that only parts conforming with the high standards leave the plant.
Storing and Shipping	The products are stored on-site and readied for shipping or for the internal machining phase.

Production processes in the plant are continuously optimised which leaves very little room for further improvements. Currently the failure rate (products that do not meet the stringent quality standards) lies at around 4%.

The use of ALCHIMIA in the context of this plant is designed to overcome an inherent problem related to the production of cast iron car parts: some important quality checks can only be performed after a significant period of time passes, due to the need for products to have cooled down sufficiently. Occasionally, faults affecting a whole batch of products are only discovered at this late stage. This also means that production of sub-optimal products will have continued for several hours (between 3 and 7 hours) and the whole batch will have to be scrapped. The ALCHIMIA system is supposed to be used in the context of the automotive parts production to predict the quality of final products based on a range of data characterising material input and production processes.

3 ALCHIMIA and its Functions

3.1 Introduction

ALCHIMIA refers to an interactive system in the form of a digital platform that utilises two specific approaches to machine learning (ML), Federated Learning (FL) and Continual Learning (CL), to help European metallurgy industries to continuously optimise production processes. In doing so, ALCHIMIA aims to support the development of high-quality, competitive, efficient and green production processes.

ALCHIMIA as an interactive digital system is supposed to fulfil different functions in the context of the two above described use cases. In the case of EAF plants, ALCHIMIA is supposed to make more accurate predictions concerning ingredients and production parameters, while in the case of the plant producing automotive parts, the system will be used to accurately predict final product quality.

In the terms of the ALCHIMIA project proposal, '*ALCHIMIA will develop a federated learning and continual learning solution aiming to help any industry to improve the efficiency of their strategies to support the green deal. For that, the consortium will focus on two specific sectors, which have some commonalities: steel and automotive components. Pilot objectives: A) Developing disruptive process optimisation solutions based on AI and data; B) Feeding AI/machine learning systems with lessons from other factories to increase the impact of the solutions; and C) Learning from other factories to make solution replication easier. The overall ALCHIMIA concept will rely on the combination of two innovative paradigms: Federated Learning and Continual Learning.*'

3.1.1 Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) is the area of study that simulates human intelligence in machines or computer systems. AI systems aim to replicate and enhance human cognitive abilities, allowing them to analyse large amounts of data, recognize patterns, adapt to changing environments, and perform tasks with autonomy.

Machine Learning (ML) is a branch of Artificial intelligence that focuses on improving system performance by learning from experience using computational methods. It is a very wide domain that derives from other related fields, including computer science, statistics, and optimization. In computer systems, experience exists in the form of data, and the main task of ML is to develop learning algorithms that build models from experience data. These models, once created, can make predictions based on new observations (see Zhou 2021).

Machine Learning can be employed to tackle a variety of challenges. The three most important types of problems that can be solved via ML are classification, regression, and clustering. When the output of a prediction is discrete, it is referred to as a classification problem, while when it is continuous, it is named as regression. The clustering problem involves grouping data into clusters (or groups), according to their intrinsic similarities.

Furthermore, ML can be divided into several learning paradigms based on the annotation of the data used (see Zhang and Lu 2021). These types are supervised learning, unsupervised learning, and semi-supervised learning:

- In supervised learning, the model is created using a labelled training dataset to extract the relationship between the input samples and the true labels.

- Unsupervised learning is a learning paradigm where the model is trained without explicit supervision or labelled dataset. The objective is to find similar characteristics and structures across the input samples.
- Semi-supervised learning is a hybrid learning paradigm where the input dataset is partially labelled, and the unlabelled data samples largely exceed the number of labelled samples.

3.1.2 Federated Learning

Federated Learning (FL) is defined as an approach to Machine Learning that enables a collaborative training model based on multiple local datasets contained in local devices without exchanging data samples, thus keeping it decentralized. This approach avoids the necessity of gathering large amounts of data from different sources and transfer it to a central server. By decentralizing the training process, FL not only preserves data privacy but also reduces data transfer overhead, making it an efficient and resource-saving alternative (see also ALCHIMIA D3.1 Federated Learning infrastructure implementation).

Starting with a global model on a central server a training round or iteration in FL is described as follows:

- The clients that will participate in the training are identified.
- The global model is broadcasted to the client devices.
- Each client computes a local update on the model using their local data.
- The central server collects the local models from the clients and aggregates them creating a global model.

After several training rounds, the global model performance is tested before deployment.

As described in the iteration steps, the central server plays a critical role in the FL system. The server is responsible of aggregating the local model updates provided by the clients. The process of aggregating is essential in determining the quality and performance of the resulting global model. There are different aggregation mechanisms available in the literature, including Federated Averaging (FedAvg), Federated Weighted Averaging (FedWeightedAvg), and Federated Stochastic Gradient Descent (FedSGD).

Although FL preserves user privacy by decentralizing data it does not fully guarantee security. Studies have shown that attackers may steal personal data from edge devices, attack the communication process, or compromise the global model training process. By making use of the right privacy preserving techniques these privacy leaks are reduced. The primary methods for privacy protection in FL are Differential Privacy, Homomorphic Encryption, Secure Multiparty Computation, and Private Aggregation of Teacher Ensembles (see Banabilah et al. 2022).

Within the ALCHIMIA project, a FL framework will be specifically developed to address the requirements of the metallurgy sector, where ML models must be developed without sharing data even between factories that belong to the same group. Multiple aggregation algorithms and privacy preserving mechanisms will be integrated into the solution to adjust the performance to different use-cases. Local adaption and Transfer Learning techniques will be applied to fight against accuracy problems of federated models.

3.1.3 Continual Learning

One of the problems during the deployment of ML models in production environments is called domain shift, which causes significant drops in the model performance when input data is slightly different with respect to the training datasets.

Continual Learning (CL) mechanisms repeatedly monitor the performance of the deployed models in order to adapt and learn from new streams of data. When the performance of the model has fallen below a certain threshold, a retraining is triggered, resulting in a newer version of the model. The objective in this process is to keep useful past knowledge while acquiring further knowledge of recent data.

The most important challenge in CL is to avoid catastrophic forgetting. This Machine Learning phenomenon occurs when a model that was trained on a sequence of tasks or datasets forgets significant information from previous tasks when being retrained. Different solutions exist for prevent and mitigate this challenge, such as storing past data or using regularization methods (see Lesort et al. 2020).

ALCHIMIA will implement and demonstrate a Continual Learning system so that models' performance can be monitored once they are deployed, triggering retraining processes to overcome domain shift issues, and improving the robustness of ML models. Additionally, the retraining processes will make use of a Federated Learning strategy where all the data from the clients will be used to enrich new models. The combination of these two approaches will ensure the long-term adaptivity of the solution with low maintenance requirements.

3.1.4 The ALCHIMIA System

The ALCHIMIA project will produce the following new or enhanced tools for scrap characterisation, process monitoring, optimisation and decision support and embed them in the overarching AI framework that will be used to improve the economic impact and environmental sustainability of the metal making processes involved in the project's two use-cases:

- The **material feedstock will be characterised by advanced statistical analysis methods**. Different properties of the feedstock materials as chemical composition, yield, bulk density and specific meltdown energy demand can be estimated by analysis of historical data. For each batch, the charged materials, the tap weight, the total energy input and the achieved composition and temperature of the metal melt are evaluated. These methods are effective for estimation of average values of selected elements in the scrap chemistry, specific energy consumption and yield coefficients for frequently used materials with relatively stable properties. The estimations of charge material properties will form the base for a charge material mix optimisation as well as model-based process monitoring and control tools. To cope with the higher variability of the feedstock materials, besides the classic optimisation methods a set of innovative data analytics tools will be implemented with the aim to establish the hidden correlations between system inputs (scrap quality) and outputs (product quality).
- A **charge mix optimisation** will be applied to select the eco- and cost-optimal mix of scrap types and alternative charge materials for production of each product quality, e.g., of liquid steel ingots, which are defined by the chemical composition. Besides the purchase costs, also the costs for energy supply to melt down the different charge materials will be considered as well as the environmental impact of each scrap type, as this can significantly affect the optimisation result. In addition to several operational restrictions like the volume of the charging vessel or maximum amounts of certain scrap types, also the current availability of the different charge material types will be considered by establishing a database connection to an online inventory control system.

- **On-line monitoring and prediction of the steel melting process behaviour** will be mainly based on mathematical models using energy and mass balance calculations in combination with AI-assisted model optimisers. Such hybrid dynamic energy and mass balance models allow the continuous calculation of the melt temperature based on the specific meltdown energy demand of the charged materials and the electrical and chemical energy input. With the modelling of the metallurgical reactions which are performed during the melting and refining process, also the chemical composition of the metal melt can be calculated continuously.
- **Holistic and computationally efficient data-driven ML-based approaches** will be applied for modelling processes in the steel production chain, which follow the melting and refining process. These models will be mainly focused on the evaluation of parameters, which correlate "scrap recipe" to product quality or which are relevant for assessing the environmental impact of the whole production chain.
- **Hybrid data-driven heuristic approaches** can also be used, if appropriate, such as equation-based simplified parametric models, whose parameters are automatically tuned based on the available data according to a traditional identification procedure or based on evolutionary approaches.
- **ML-based and hybrid approaches will also be adopted in the case of the automotive components' foundry**.
- An **optimisation framework** will be developed considering qualitative objectives and LCA-related objectives, which integrates and exploits the developed models.
- **Comparative LCA** studies will demonstrate the steel and foundry products environmental footprint and the production processes to improve. In addition, the LCA implementation will allow the internalization of Life Cycle Thinking models by CELSA and FDT driving the future company's decision-making process to greener and sustainable solutions.
- **Model Predictive Control strategies and multi-objective evolutionary approaches** will be considered for the optimisation.

3.2 ALCHIMIA and the optimisation of EAF steelmaking

A functioning ALCHIMIA system will be able to optimise EAF-based steelmaking processes insofar as it will lead to reduced energy consumption, emissions and waste generation while maintaining product quality. The core capabilities of ALCHIMIA will be to propose an 'optimal scrap mix' and to suggest an optimal melting process. Additionally, ALCHIMIA should also contribute to improved planning of scrap purchasing by continuously monitoring the scrap inventory.

Figure 1 summarises the processes involved in the determination of the magic recipe, as well as the approach to optimise each of the steps by combining already available tools and data with newly developed solutions by each partner to be validated during the project.

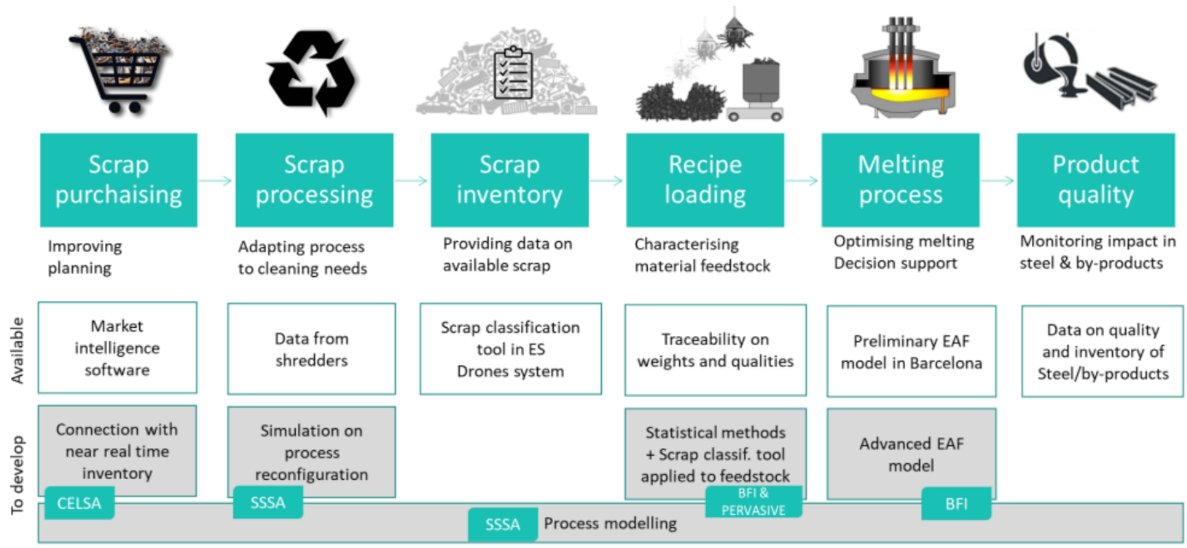

Figure 1: Finding the 'magic recipe' for EAF steelmaking

There are a number of challenges that ALCHIMIA needs to tackle to allow it to function in the desired way.

First, for ALCHIMIA to work, the accuracy or precision of a number of measurements of processes that are part of the processes that are to be optimised needs to be improved.[4]

- **Incomplete scrap characterisation**: Determining the composition of the actual charge mix entering the furnace is necessarily imprecise and incomplete unless every piece of scrap metal is cleaned and completely analysed. This is practically impossible due to the costs involved, the time this would take and space restrictions on scrap yards. Using technology such as I-Scrap, an AI-based scrap classification currently trialled in one of the participating plants, should, however, allow to increase the precision of classification as well as improve estimates about impurities and residuals within scrap heaps.
- **Imprecise Basket Charging**: Charging the scrap in the basket is inevitably imprecise to some extent. First, recipes specify scrap weights only up to a certain degree – the smallest weight unit encountered in the steel plants appeared to be 100 kg which suggests that quantities specified by recipes can only be followed to a certain degree of accuracy. Secondly, scales are also utilised to measure how much is really loaded into the basket, but these scales also only specify weight up to a certain degree.[5] Thirdly, basket loading is also a manual activity that requires trained and competent crane drivers. Improved training might result in greater precision with regard to basket loading.

[4] The project proposal suggests that these can be solved, but, at best, accuracy or precision can be improved without ever achieving complete accuracy or precision.

[5] Even if the weight of what is loaded into the basket could be specified down to grams, the incomplete characterisation of scrap (previous point) means that absolute precision with regard to basket loading is not possible.

- **Incomplete characterisation of melting process**: There is only very limited information from physical sensors under the very harsh conditions in the furnace, which makes it currently impossible to fully understand what is going on inside furnaces. Thus, for dynamic process monitoring and control purposes, mathematical-physical models in combination with statistical and data-driven models, which at best approximate understanding of real-time processes, have to be used and relied on. One of the main objectives of the ALCHIMIA project is thus to improve the understanding of the relationship between characteristics of various charge material and energy demand. More precise capture of these relationships would lead to significantly higher model accuracy. Furthermore, the existing first principle process models will be enhanced by implementing AI solutions for online parameter estimation and optimisation. Such a hybrid approach will ensure long-term stability and robustness of the process models while improving the accuracy and conserving the interpretability of the results.
- **Incomplete understanding of relationship between charge mix, melting process and outcomes in terms of product quality**: Improving the precision and accuracy of the three previous issues will allow a better understanding of the relationship between charge mix, melting process and outcomes in terms of product quality, which will allow ALCHIMIA to suggest optimal mixes and optimal melting process parameters to achieve the stated goals of improving efficiency, environmental impact and resource use.

Second, once the magic recipe has been determined, melt shops will need to secure the availability of the necessary ingredients. For that, innovative technologies to get real-time scrap inventories need to be applied in order to provide scrap purchasers with the necessary information for them to plan purchases accordingly. Interviews with scrap purchasers in the three participating plants suggest, however, that there are limits to what ALCHIMIA can achieve in this area. On the one hand, even without ALCHIMIA, scrap purchasers base their purchasing already on data related to future production schedules which in turn are based on orders from customers. This means that scrap purchasers can already plan scrap purchasing to some extent. On the other hand, the main problem scrap purchasers face is not that they do not know what to buy, but that they operate in a sellers' market that makes it economically unviable to purchase scrap in an entirely planned and prescribed way. In fact, it is an economic necessity when operating in the scrap metal market to remain flexible and to avoid being forced to buy certain scrap qualities. If scrap purchasers would go into this market with a definite list of scrap grades they need to buy, scrap dealers would raise their prices which in turn might negatively affect the economic viability of steel production in the plant. A scrap buyer in one of the participating plants expressed a view shared by scrap purchasers in the other plants:

> *'This situation is quite hard because the scrap purchasing is the special market... Scrap, if you ask to someone, we need 3000 tonnes of frag next week, and this is the worst case, you know, because in that moment they are going to kill you in terms of price'* (CELF3).
>
> *'The suppliers, not only in Poland, I guess, is all over the World, are tending to be less stable. I mean they, and this is the tendency that is my experience during the last 20 years, always had a tendency to be speculating and not being stable...Obviously the decisions they make is based on the price. The price goes down, the volume goes down...they choose according to the price' (CELP4).*

While these challenges will make it difficult, if not impossible for ALCHIMIA to achieve 'absolute optimisation' it should still lead to significant relative improvements compared with current recipes. According to the ALCHIMIA project proposal, optimisation of basket charges and meting processes should lead to the following quantifiable improvements:

- Reduction of specific electrical energy input of about 10 kWh/t;
- Reduction of power-on time by about 1 minute, and of the tap-to-tap time by about 3 minutes;
- Savings of total oxygen consumption by 5%;
- Increase of metallic yield by 2%;
- Less consumption of deoxidation materials due to less over-oxidation at melt tapping by 5%;
- Increase of productivity in ton of liquid steel per hour by 3%;
- Increase of circularity ratio of scrap by 5%.

3.3 ALCHIMIA and the Production of Automotive Parts

In contrast to the application in EAF steel plants, which prescribes inputs and process configurations to reach optimal outcomes, the main function of ALCHIMIA in the context of the foundry is to predict outcomes. A second function of ALCHIMIA is to afford the holistic optimisation of the whole production process. In practice this means that ALCHIMIA will work in far less intrusive ways in foundries than it will work in steel plants.

ALCHIMIA aims to solve two problems for FDT. First, it provides a means to effectively eradicate the time between producing parts (when liquid metal is poured into the moulds) and having a final verdict that products adhere to rigorous quality standards. At the moment, lag time between production and certainty about final product quality can be between 3 and 7 hours. The reason for this is that certain quality tests such as testing acoustic emissions, porosity, cementite build up or micro-shrinkages can only be meaningfully performed once the produced part has sufficiently cooled down, which simply takes time.

Two facts explain the need to shorten this lag time: first, products deviating from the high quality standards need to either be reworked or, if the deviation is too big, they have to be scrapped. Both these things create additional costs. Second, due to the continuous production, faults related to the properties of the liquid metal leading to deviations from quality standards (for example, wrong levels of carbon in the cast iron) force the company to scrap at least all car parts produced in the previous 3 hours (with up to 7 hours of lost production in the worst case). While the material used in sub-standard products can be recycled within the company (by reusing it as scrap input for the cupola furnace), the energy and labour costs expended during the period are lost. ALCHIMIA's function in this context is to analyse a great range of production-related data to continuously predict quality outcomes before actual quality tests can happen.

Second, process optimisation is currently entirely focused on quality to ensure that final products conform with prescribed quality standards. This focus on quality also means that considerations of energy efficiency and environmental performance are currently neglected. ALCHIMIA, by modelling the production process starting at the stage of pouring liquid metal into moulds[6], will allow holistic optimisation of the production process by exploiting ML-based, first principle and hybrid approaches. The optimisation framework provided by the ALCHIMIA system will allow the company to ensure compliance of products with customers' specifications while also allowing to minimise costs and reduce the environmental impact of production.

According to the ALCHIMIA project proposal, the following estimations of savings can be given, compared with the baseline scenario and referred to single lots of production (i.e., typologies of products identified through specific part numbers):

- Reduction of energy consumptions of about >3%.
- Reduction of wasted material of > 20%.
- Reduction of CO_2 emissions > 3%.
- Reduction of scrap material or downgrade material > 10%.
- Moreover, thanks to the Federated Learning paradigm, an investigation will be pursued to replicate the modelling and optimisation approach formerly developed for FDT to the other two foundries of the group.

[6] This means the performance of the cupola furnace is not modelled and will therefore not be optimised by ALCHIMIA. One advantage of this approach is that a future 'ALCHIMIA federation' serving the foundry sector is less restricted with regard to potential members as such a federation can accommodate foundries using a variety of furnace types.

4 User and Stakeholder Requirements and Expectations

4.1 Introduction

To accomplish building an interactive AI-based system that can help companies to achieve their aims and solve their problems, e.g. improve the efficiency and reduce the environmental impact of their production processes as in the case of the two participating companies, system requirements have to be defined. These system requirements set out and define the capabilities of the system that are needed for the it to function as desired by users and stakeholders. Accordingly, requirements are defined by the ISO Standard as a 'statement which translates or expresses a need and its associated constraints and conditions' (International Organization for Standardization 2018: 4)

The approach to define requirements and expectations employed by the ALCHIMIA project is informed by the ISO 29148-2018: Systems and software engineering – Life cycle processes – Requirements standard. The standard defines a set of different environments or levels in which different actors and considerations are relevant which inform context-specific sets requirements that constrain the design of the emerging technology to align it with a number of constraints (see Figure 2). The ISO-informed approach thus provides a blueprint to systematically identify 'technical' requirements.[7]

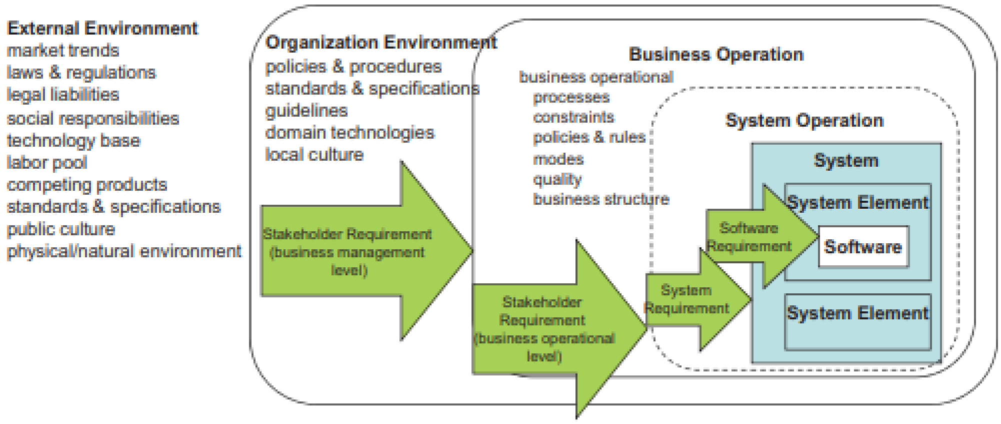

Figure 2: Requirements Framework in ISO 29148:2018 (p.20)

The most expansive context is the external environment, in which a myriad of aspects might effectively constrain or influence the design of an interactive system, ranging from the 'laws of physics' and formal laws and regulations to things like cultural norms or the availability of a skilled workforce.

[7] Further below we will contrast technical requirements with social requirements. Technical requirements are constraints and prescriptions that ultimately allow the technology to fit into specific social contexts. Social requirements demand social and not technical adaptation, i.e. the social context needs to change to allow the technology to function as intended.

Embedded in this context is the organisational environment, which has similar elements as the external environment, e.g. policies or company culture, only that these are more locally bound and usually do not go beyond the boundaries of the company. Business management and company owners are the main stakeholders at this level.

The (business) operational environment is again embedded in the two larger contexts, but the focus is on the actional operational processes, e.g. EAF-based steelmaking and manufacturing car parts in ALCHIMIA's two use cases. The main actors in this context are process-facing managers and operators who understand the processes that are to be affected by a new technology best.

The system (operation) environment refers to the actual interactive system that is to be developed. Its requirements are derived from, informed by and need to reflect the requirements identified in the other three contexts. For example, if laws prohibit the autonomous operation of a piece of technology to be developed, say a drone, then the to-be-developed drone cannot be designed as an autonomously operating aerial vehicle. Likewise, if a company has strong environmental commitments, newly developed technology should not worsen the environmental impact of the company.

This section uses the layered structure of different requirements contexts to report on the processes underpinning the definition of requirements and to present the finding of ALCHIMIA activities undertaken as part of T2.1 and T2.3, which focused mainly on the definition of operational requirements and system requirements. Technical meetings, use-case definition forms and social research have been the prime means to define these requirements.

The external and organisational requirements have been, to a large extent, defined during the project proposal development phase, i.e. before the ALCHIMIA project received approval and funding. The Assessment List for Trustworthy Artificial Intelligence (ALTAI) has been used to align the ALCHIMIA project with general external requirements for AI-based systems as set out by the High-Level Expert Group on Artificial Intelligence (AI HLEG) on behalf of the European Commission.

The analysis of requirements in the different environments culminates in the key output of this research stage, which sets out and defines the System Requirements. System Requirements should reflect, implicitly or explicitly, all technical requirements at the higher levels. The System Requirements document is reproduced in full in Appendix A.[8]

Additionally, mobilising the social scientific research component of the ALCHIMIA project, some important 'social requirements' have been identified. Social requirements refer to necessary changes to the social context in which a new technology is to be embedded to ensure the technology can function as intended. The identified social requirements are 'user acceptance', the automation of data input relevant for ALCHIMIA and investment into training and additional capacity.

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[8] The technical requirements have largely been identified using tools such as technical meetings or use case forms. It is worth noting that interviews with users and key stakeholders has reaffirmed many of the technical requirements identified by other means. The social research finding that scrap markets are 'sellers' markets' (see section ALCHIMIA and EAF Steel Making) can count as a additional technical requirement as it constrains the development of the technology insofar as the ALCHIMIA system should avoid imposing too much inflexibility on scrap buyers within companies by over-specifying how much of which scrap grade needs to be acquired when.

4.2 Overview of Requirement Elicitation Process

According to ISO 29148, both users and stakeholders should be involved in the requirements elicitation process. This also aligns with demands (or requirements) that are part of the human-centred design (HCD) process utilised by the ALCHIMIA project (see Part 4 of this report). The standard defines stakeholders as an 'individual or organization having a right, share, claim or interest in a system or in its possession of characteristics that meet their needs and expectations', while users are defined as an 'individual or group that interacts with a system or benefits from a system during its utilization.'

In the context of the ALCHIMIA project, the distinction between users and stakeholders appears to be less critical as there is great if not complete overlap between the categories. For example, while the participating companies (as legal actors) have an interest in the system, which makes them a stakeholder, they also benefit from the system during utilization if it can deliver on the efficiency promises, which makes them users. More important for the purposes of requirements elicitation, but also due to HCD commitments, is to distinguish those who are stakeholders and/or users from those who are not.

In the context of the ALCHIMIA project, stakeholders and users include the funder of the project (European Commission), the consortium members as well as many, if not all, of the employees[9], managers and operators alike, in the participating plants (see Appendix B).

A broad and diverse set of processes and tools to elicit requirements have been utilised. As indicated above, identification of requirements started at the point where prospective consortium partners started to seriously consider applying for Horizon Europe funding. The **work on the ALCHIMIA proposal** was mainly conducted remotely and online, although various partners met in person to discuss aspects of the ALCHIMIA project. The requirements identified at this stage relate mainly to the external and organisational environment.

Standardised Use Case Forms were distributed to the participating companies to define operational requirements. The forms encourage prospective users of a system to define the problems they want to solve. These are described in detail and in the context of operational processes. Users also describe what sort of data and information is available, so that developers are in a position to understand whether the problem is actually technically solvable. The completion of these forms happened iteratively, which means users, upon completing the form, would receive feedback from the developers, which would then lead to an improved version of the use case form being produced.

In 2019, the European Commission set up the High-Level Expert Group on Artificial Intelligence (AI HLEG) which eventually published the so-called ***Ethics Guidelines for Trustworthy Artificial Intelligence*** (High Level Expert Group on AI 2019). Part of these guidelines is an Assessment List to help assess whether the AI system that is being developed, deployed, procured or used, adheres to the seven requirements of Trustworthy Artificial Intelligence (High Level Expert Group on AI 2020):

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[9] If the promised efficiency gains materialise, all employees will indirectly benefit from the use of the system, which per definition would make all employees users.

1. Human Agency and Oversight;
2. Technical Robustness and Safety;
3. Privacy and Data Governance;
4. Transparency;
5. Diversity, Non-discrimination and Fairness;
6. Societal and Environmental Well-being;
7. Accountability

The assessment list is effectively a long check-list in the form of questions related to the seven requirements that developers, stakeholders and users are asked to answer. In doing so, it becomes clear which aspects, if any, of a proposed system or AI tool are not yet aligned with the requirements. This reflective process then offers developers the opportunity to revise the system design to achieve alignment with the requirements.

Technical visits were organised to allow partners responsible for technological development of ALCHIMIA to observe the processes and to provide opportunities for dialogue and trust-building between users and stakeholders located in the plants and consortium partners. Technical partners visited the FDT plant in Italy in November 2022, while a similar visit of the EAF plant in France took place in March 2023. Given that a lot of work has gone into framing the ALCHIMIA project at the proposal development stage, these technical meetings focused very much on technical details.

Social research, specifically semi-structured interviews, conducted as part of the ALCHIMIA project has also contributed to the requirements elicitation process. The main activities in this regard involved a series of two-day site visits to each participating plant to conduct a series of (often) *in-situ*.[10] Different types of actors working in the plants were interviewed, covering all aspects of production processes likely to be affected by ALCHIMIA. Interviews lasted between tended to last between 30 mins and 2 hours and were conducted in English were this was possible and in local languages were necessary. Colleagues attached to other ALCHIMIA partners acted as translators when required. Following ethical approval for the social research, informed consent was secured before each interview commenced and anonymity and confidentiality guaranteed to all participants. An anonymised overview of staff interviewed in each of the participating plants is shown in Appendix C.

[10] All plant visits took place in May and June 2023: FDT – 17/18 May; Celsa PL – 24/25 May; Celsa FR – 5/6 June; Celsa ESP – 26/27 June. All visits and the research conducted with human participants at each plant was subject to standard ethics processes and procedures. The social science aspect of the ALCHIMIA project was subject to Cardiff University's School of Social Science's SREC (Social Research Ethics Committee) and received clearance (SREC Ref. 304) to proceed from the committee. Standard ethical procedures for anonymisation and confidentiality, as well as informed consent, were followed.

4.3 External and Organisational Requirements

Table 3 below provides a brief overview of requirements related to the external and the organisational environment which also specifies where these requirements emanate from. Table 3 concentrates on the most relevant and important requirements, i.e. on those explicitly mentioned in the ALCHIMIA project proposal.[11]

Table 3: Overview of External and Organisational Requirements

Context	Requirements	Sources/ Basis
External Environment	GHG emission reduction	EU Green Deal, Next Generation EU Recovery Plan
	Increased Circularity of resource use	EU Green Deal, Next Generation EU Recovery Plan
	Ethical and trustworthy use of AI	Ethics Guidelines for Trustworthy Artificial Intelligence
	Data Privacy and Safety and Business Confidentiality	GDPR, IP Law
	Push for Industry 4.0, automation and digitalisation at EU level	EU Green Deal (role for AI)
	Reduction of energy consumption	EU climate targets
	Human-Centric Design	EC Policy Brief on Industry 5.0
Organisational Environment	Reduce costs	Stakeholder/User collaboration during development of project proposal
	Improve efficiency (resource use, reduce waste)	
	Exploit collected and collectable process data	
	Protect data	
	Reduce emissions	

[11] In reality, there are likely to be thousands of 'requirements' linked to the external environment, including the 'laws of physics' and countless local, national and supranational laws and regulations that are more or less implicitly relevant for ALCHIMIA. Obviously, an exhaustive and complete requirements analysis is not possible, but intense and structured engagement of a set of diverse actors with requirements should identify those that are the most relevant and impactful. Interviewees mentioned a diverse set of issues, including Euro7 Regulations for brake discs (FdT1), French government energy subsidy schemes (CELF3), different pricing for energy depending on the time of the day (CELF5), regulation on use of video cameras in work places (CELF7 and 8), national scrap norms (CELP1) and varying conditions of electric grids in different parts of Europe (CELP3). Drawing up a complete catalogue of requirements is therefore likely to be impossible, but a combination of requirement elicitation tools and an intense and inclusive elicitation process should identify those that are directly or particularly relevant for ALCHIMIA.

Context	Requirements	Sources/ Basis
	Improve quality Improve productivity Increase/ Improve 'circularity'	

Most of the requirements related to the external environment listed in Table 3 are based on policies or regulations at EU and national level. In the majority of these cases, the sources for these requirements provide enough guidance and information to steer activities in the ALCHIMIA project.

A specific case amongst the external requirements are the requirements for trustworthy AI that have been developed by a dedicated independent expert group on behalf of the European Union. The Ethical Guidelines formulate requirements that AI-based technological developments ought to conform with, but the development team still needs to carry out a self-assessment, which is referred to as ALTAI process. ALTAI stands for Assessment List for Trustworthy Artificial Intelligence. The self-assessment falls into two parts. First, the guidelines suggest that any AI-based technology needs to comply with 4 fundamental rights. The relevant self-assessment is shown in Table 4 below:

Table 4: ALCHIMIA compliance with 4 fundamental rights

Fundamental Rights	ALCHIMIA Project Self-Assessment
Does the AI system potentially negatively discriminate against people on the basis of any of the following grounds (non-exhaustively): sex, race, colour, ethnic or social origin, genetic features, language, religion or belief, political or any other opinion, membership of a national minority, property, birth, disability, age or sexual orientation?	No – ALCHIMIA system does not use personal data of any kind and has no discernible effect on individuals or groups of people
Does the AI system respect the rights of the child, for example with respect to child protection and taking the child's best interests into account?	Yes – ALCHIMIA has no impact on children
Does the AI system protect personal data relating to individuals in line with GDPR?	Yes – no personal data are collected
Does the AI system respect the freedom of expression and information and/or freedom of assembly and association?	Yes – data sharing within ALCHIMIA system is voluntary and has no impact on anyone's freedom of expression, information, assembly and/or association

The second part of the self-assessment focuses on seven general requirements that an AI-based technology needs to comply with to have a chance to be considered trustworthy.[12] Table 5 provides an overview of the requirements, respectively related issues or themes and the status of the ALCHIMIA self-assessment with regard to each requirement.

Table 5: ALCHIMIA Self-Assessment of 7 Requirements for Ethical and Trustworthy AI

Requirement	Particular Issues	Status
Human Agency and Oversight	Human Agency Human Oversight	Fully considered
Technical Robustness and Safety	Resilience to Attack and Security General Safety Accuracy Reliability, Fall-Back plans and reproducibility	Fully considered
Privacy and Data Governance	Privacy Data Governance	Fully considered
Transparency	Traceability Explainability Open communication about the limitations of the AI system	Fully considered
Diversity, Non-discrimination and Fairness	Avoidance of Unfair Bias Accessibility and Universal Design Stakeholder Participation	Fully considered
Societal and Environmental Well-being	Environmental Wellbeing Impact on Work and Skills Impact on Society at large and Democracy	Fully considered
Accountability	Auditability Risk Management	Fully considered

[12] Steve Shapin, a historian of science, has convincingly argued that there is no 'theory of trust' that might provide us with a clear methodology to create trust. The 'problem' (or rather the reality) is that any sort of contingent factors far removed from the actual matter in hand – for example, the physical looks of central actors or the type of font chosen in written communication about a technology - can impact trust relations (Shapin 1995). Compliance or alignment with the fundamental rights or any of the other requirements set out by ALTAI does therefore not guarantee that people will trust the technology. Compliance does, however, provide arguments that can be used to persuade people that an AI-based technology can be trusted.

The organisational requirements have also been mainly identified during the preparatory stages of the ALCHIMIA project. They have entered the project proposal in the form of specific objectives (see Table 3 above) that developers need to keep in mind so that the ALCHIMIA system is capable to meet these targets.

4.4 Operational Requirements

Operational requirements have mainly been identified using so-called Use Case Forms. CELSA has identified one scenario with 7 connected use cases (see Table 6).

Table 6: Summary of CELSA Use Case Form

Scenario	Use Cases	Description
Scenario 1	**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).
	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…)

Scenario	Use Cases	Description
	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.

FDT has identified 2 scenarios with 2 and 3 related use cases respectively (see Table 7).

Table 7: Summary of FDT Use Case

Scenarios	Use Cases	Description
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).	**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

Scenarios	Use Cases	Description
		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: ex-ante evaluation of the	**Use case 1**	Prediction model to evaluate ex-ante output data (output parameters are shown in use

Scenarios	Use Cases	Description
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.		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.

4.5 System Environment

The main output of activities related to requirements elicitation is the document that sets out functional and non-functional system requirements. These requirements specify the capabilities and functionalities of the system. The system requirements derived from the beforementioned Use Cases and the project objectives. Functional requirements refer to the features, functions, and capabilities that the ALCHIMIA system must provide to meet the needs of its users. Non-functional requirements specify the quality characteristics or constraints that the system must satisfy, such as performance, reliability, security, and usability. They must reflect or at least be compatible with all the requirements identified at the three higher levels. A total of 38 functional and 20 non-functional requirements have been identified (see Appendix A).

4.6 Social requirements

Given the importance of System Requirements for the development process, unsurprisingly most activities related to the requirements elicitation process were directed towards identifying 'technical requirements' which we define as requirements that impact on the design and functioning of the technical system that is to be built. The underlying idea, which is also compatible with the Human-Centred Design approach, is that the technology needs to be designed and ultimately made to work in ways that fit as much as possible into social settings without leading to undesirable consequences.

Unfortunately, technology design alone is usually not capable to ensure that the technology works as intended while minimising undesirable consequences. The social environment into which technologies are to be inserted also has a role to play in the smooth working of technology and the avoidance of negative consequences. An obvious aspect to illustrate this point is that any technological system requires repair and maintenance, but qualified maintenance staff is not an inherent 'technical' part of the system: companies using a technological system need to ensure that maintenance and repair capacity is available when needed. While there are different strategies companies can pursue – for example, create their own maintenance capacity or buy-in external maintenance capacity – what is clear is that they need to do something, i.e. change the social context in some way, to allow technology to fit in and to work as intended.

We use the term 'social requirements' to refer to those necessities that are imposed on the social context to ensure that technological systems inserted in this context work as intended and with minimal undesirable consequences. Paying attention to social requirements is an integral part of the ALCHIMIA project through its alignment with human-centred design principles and the EU Guidelines for Ethical and Trustworthy AI. In the remainder of this section, we consider, analyse and discuss three social requirements which have importance and relevance for the ALCHIMIA project.

4.6.1 User Acceptance

Perhaps the most general or basic 'social requirement' in the context of technology insertion is 'user acceptance'. Without user acceptance, there is a considerable risk that new technologies will not work as intended. Further, user acceptance is necessary across the occupational hierarchy. Management and those responsible for investments in technological innovation must be convinced of its cost-benefit to the firm. Those using the technology on a day-to-day basis must be convinced that it is not a threat to the material realities of their employment and should contribute to decent work, rather than result in job loss, de-skilling, routinisation and so on. There might be tensions between management and workers on the insertion and non-insertion of technology. Management, for example, may not fully understand the potential 'degree of success' offered by a technological innovation – a management with a productivist ethos may not be willing to tolerate the disruption technology insertion may create (Edwards and Ramirez, 2016). Workers, however, might more fully understand the benefits a technology might bring – both with regard to its direct and indirect effects.

The sociologically oriented literature on user acceptance of technological systems suggests a number of issues that can positively or adversely affect user acceptance of new technologies (Edwards and Ramirez, 2016; MacKenzie et al. 2017; Stroud and Weinel, 2020). The social research conducted for ALCHIMIA has focused on seven issues:

1. Impact on Competences and Skills
2. Impact on Work Flow

3. Impact on Privacy
4. Impact on Agency and Control
5. Impact on Job Security
6. Impact on Work Relationships
7. Impact on Occupational Health and Safety

Interestingly, these issues cover or entail almost all the requirements as identified by the Ethics Guidelines for Trustworthy AI as these also seek to create a favourable social context for technology insertion (see Table 5 above). Table 8 below shows that the relationship is not simple or linear, but that individual ethical requirements can be related to a number of acceptance factors. This also means that an analysis of the sociologically relevant issues implicitly also analyses issues related to ethics and trustworthiness of ALCHIMIA.

Table 8: Relationship between acceptance factors identified by literature and Ethics Guidelines

Acceptance Factors	Issues	Ethics Guidelines
Impact on Competences and Skills	Deskilling, Upskilling, Retraining	Human Agency and Oversight Diversity, Non-discrimination and Fairness
Impact on Work Flow	Work intensification, changing tasks, 'routinization of work'	Diversity, Non-discrimination and Fairness Human Agency and Oversight
Impact on Privacy	Surveillance, Dataveillance, Function Creep, Cybersecurity	Privacy and Data Governance Transparency
Impact on Agency and Control	Autonomy and discretion Work organisation	Human Agency and Oversight Transparency Accountability
Impact on Job Security	Job losses, increased precarity, loss of benefits	Diversity, Non-discrimination and Fairness Societal and Environmental Well-being
Impact on Occupational Health and Safety	Accidents, Ergonomics, Wellbeing	Technical Robustness and Safety
Impact on Employment Relationships	Conflict Work organisation	Diversity, Non-discrimination and Fairness

We can illuminate the issue of user acceptance from two different perspectives. One is directly based on the user and stakeholder views of and attitudes towards ALCHIMIA.[13] The other is based on a sociological evaluation of the likely impacts of ALCHIMIA.

User views of, and attitudes towards, ALCHIMIA have been mainly gathered via standardised surveys. Currently a total of 37 completed surveys have been returned.[14] This relatively low number is insufficient for all but the most basic analysis and means results have to be treated with great caution. The limited survey data suggest that support for ALCHIMIA among respondents to the survey is generally high and that they regard ALCHIMIA as a useful and welcome technological development. Whether this also reflects the views across the wider workforce in the companies is unclear.

In general, respondents indicate strong support for the aims and objectives of the ALCHIMIA project (see Tables 9, 10, and 11).

Table 9: User views on ALCHIMIA's environmental objective

Question:	The ALCHIMIA Project has a number of different objectives, with some of them having the potential to affect the metal sector in some important ways. From your personal point of view, how supportive are you of the different aims? **Support the green transition of the European metal and steel sector**		
	Total	FDT	CELSA (combined)
Support	100% (37)	100% (12)	100% (25)
Undecided	0% (0)	0% (0)	0% (0)
No support	0% (0)	0% (0)	0% (0)

Table 10: User views on ALCHIMIA's optimisation objective

Question:	The ALCHIMIA Project has a number of different objectives, with some of them having the potential to affect the metal sector in some important ways. From your personal point of view, how supportive are you of the different aims?

[13] In sociological theory, we can rely on both actors' and analysts' perspectives. The former tends to be based on direct lived experience, while the second one is based on deliberate research efforts, the results of which are then interpreted by social researchers.

[14] All four participating plants have a total combined workforce of more than 1,500 staff, which makes the return rate extremely disappointing. To some degree, however, this is in line with previous experience of using surveys as a research tool in manufacturing settings.

	To create a system using artificial intelligence (AI) to automatically find the optimal mix for scrap-metal based steelmaking processes		
	Total	FDT	CELSA (combined)
Support	92% (34)	92% (11)	92% (23)
Undecided	3% (1)	0% (0)	4% (1)
No support	5% (2)	8% (1)	4% (1)

Table 11: User views on ALCHIMIA's ethical objective

Question:	The ALCHIMIA Project has a number of different objectives, with some of them having the potential to affect the metal sector in some important ways. From your personal point of view, how supportive are you of the different aims? **Guarantee the highest levels of trust, safety and seamless collaboration between workers and AI-powered industrial solutions**		
	Total	FDT	CELSA (combined)
Support	89% (33)	92% (11)	88% (22)
Undecided	8% (3)	0% (0)	12% (3)
No support	3% (1)	8% (1)	0% (0)

When asked about their overall disposition towards the ALCHIMIA project and its aims, the vast majority of respondents indicate moderately or extremely positive views, while no negative views were recorded (see Table 12).

Table 12: User views on ALCHIMIA project and its aims

Question:	**Based on your current awareness and understanding of the ALCHIMIA project, what is your overall view of the project and its aims?**		
	Total	FDT	CELSA (combined)
Extremely positive	30% (11)	33% (4)	28% (7)
Moderately positive	54% (20)	42% (5)	60% (15)
Neither positive nor negative	16% (6)	25% (3)	12% (3)
Moderately negative	--	--	--

Extremely negative	--	--	--

Asked about a number specific 'user acceptance factors' mentioned above, respondents generally express positive views (see Table 13 - 19).

Table 13: User views on ALCHIMIA's impact on tasks

Question:	**ALCHIMIA will affect the tasks that I perform as part of my job**		
	Total	FDT	CELSA (combined)
Positive impact	57% (21)	50% (6)	60% (15)
No or neutral impact	30% (11)	42% (5)	24% (6)
Negative impact	8% (3)	8% (1)	8% (2)
Don't know	5% (2)	-	8% (2)

Table 14: User views on ALCHIMIA's impact on autonomy

Question:	**ALCHIMIA will affect my job autonomy**		
	Total	FDT	CELSA (combined)
Positive impact	32% (12)	25% (3)	36% (9)
No or neutral impact	54% (20)	67% (8)	48% (12)
Negative impact	5% (2)	8% (1)	4% (1)
Don't know	8% (3)	-	12% (3)

Table 15: User views on ALCHIMIA's impact on job security

Question:	**ALCHIMIA will affect my job security**		
	Total	FDT	CELSA (combined)
Positive impact	24% (9)	25% (4)	20% (5)
No or neutral impact	59% (22)	58% (7)	60% (15)
Negative impact	-	-	-
Don't know	16% (6)	8% (1)	20% (5)

Table 16: User views on ALCHIMIA's impact on skills and competences

Question:	ALCHIMIA will affect my skills and competences		
	Total	FDT	CELSA (combined)
Positive impact	59% (22)	67% (8)	56% (14)
No or neutral impact	27% (10)	25% (3)	28% (7)
Negative impact	5% (2)	8% (1)	4% (1)
Don't know	8% (3)	-	12% (3)

Table 17: User views on ALCHIMIA's impact on work relationships

Question:	ALCHIMIA will affect my relationships with my colleagues		
	Total	FDT	CELSA (combined)
Positive impact	27% (10)	33% (4)	24% (6)
No or neutral impact	59% (22)	50% (6)	64% (16)
Negative impact	-	-	-
Don't know	14% (5)	17% (2)	12% (3)

Table 18: User views on ALCHIMIA's impact on work intensity

Question:	ALCHIMIA will affect the intensity of my work		
	Total	FDT	CELSA (combined)
Positive impact	30% (11)	25% (3)	32% (8)
No or neutral impact	54% (20)	67% (8)	48% (12)
Negative impact	5% (2)	8% (1)	4% (1)
Don't know	11% (4)	-	16% (4)

Table 19: User views on ALCHIMIA's impact on privacy

Question:	ALCHIMIA will affect how my work is controlled by others		
	Total	FDT	CELSA (combined)
Positive impact	16% (6)	17% (2)	16% (4)
No or neutral impact	62% (23)	67% (8)	60% (15)
Negative impact	5% (2)	8% (1)	4% (1)
Don't know	16% (6)	8% (1)	20% (5)

The survey research also suggests that there is some limited potential for strained employment relations as a consequence of inserting ALCHIMIA into production processes. Given the strong support for the aims and objectives of ALCHIMIA this potential for conflict might be more related to the way in which ALCHIMIA is to be inserted than to the technology itself as the survey results above suggest. When asked in general terms about technological innovations and whether their respective companies tended to involve affected staff at an early stage, whether they received the required training and support and whether their views are taken seriously, the following results emerged (see Tables 20 – 23).

Table 20: User views on their company's commitment to engagement with staff affected by change

Question:	In general, my company tends to involve all people affected by change into the planning stage.		
	Total	FDT	CELSA (combined)
Tend to agree	84% (31)	83% (10)	84% (21)
Tend to disagree	16% (6)	17% (2)	16% (4)

Table 21: User views on their company's commitment to take into account the views of staff affected by change

Question:	In general, the views of people affected by change are taken seriously.		
	Total	FDT	CELSA (combined)
Tend to agree	86% (32)	75% (9)	92% (23)
Tend to disagree	14% (5)	25% (3)	8% (2)

Table 22: User views on their companies commitment to provide required training to staff affected by change

Question:	In general, my company tends to provide staff with the training they need before changes come into effect		
	Total	FDT	CELSA (combined)
Tend to agree	86% (32)	92% (11)	84% (21)
Tend to disagree	14% (5)	8% (1)	16% (4)

Table 23: User views on their companies commitment to provide initial support to staff affected by change

Question:	In general, sufficient support is provided to deal with initial problems.		
	Total	FDT	CELSA (combined)
Tend to agree	81% (30)	92% (11)	76% (19)
Tend to disagree	19% (7)	8% (1)	24% (6)

Continued commitment to human-centred design as well as continued efforts to communicate and engage with staff on relevant aspects of ALCHIMIA should help to minimise the risk of rejection by users.

Adopting a socio-analytical (or analysts') perspective, our overall assessment is that the **ALCHIMIA system is unlikely to face much user resistance** as it has only very limited potential to negatively affect the various user acceptance factors. ALCHIMIA aims to optimise existing processes without radically changing or transforming them. Instead, the main approach is to improve some of the existing production steps, thereby improving the overall efficiency of the process. This also means that the impact of ALCHIMIA on the vast majority of jobs in the participating plants is indirect or negligible.

There are, however, some very limited and specific areas of the respective production processes where the impact of ALCHIMIA will be noticeable. Within the context of EAF steelmaking, this concerns mainly recipe selection and furnace control, while in the context of producing automotive parts, one specific operator job is likely to undergo some limited changes to support the functioning of the ALCHIMIA system.

A summary assessment is provided in Table 24.

Table 24: Summary assessment of factors influencing user acceptance

Acceptance Factors	Issues
Impact on Competences and Skills	Overall, the use of ALCHIMIA is likely to lead to additional skill and competence needs (see discussion on 'Additional capacity and competence needs' further below in this section). Given the small

Acceptance Factors	Issues
	transformational potential of ALCHIMIA, it is unlikely that many of the currently require skills and competences will become obsolete. Rather, it is likely that using ALCHIMIA will create need for new competences related to installing and maintaining sensor infrastructure and collecting, storing and analysing production-related data. *Those who currently manage production will obviously need to be introduced to the system, be able to read it and understand the forecasts that are given to them, and if all the data is transmitted to them correctly. Training will be necessary. (FdT1)*
Impact on Work Flow	The effects of ALCHIMIA on the work flow are overall very small and limited to a tiny number of jobs. Additional tasks might be needed to support ALCHIMIA while a working ALCHIMIA system might also intensify work. For example, at FDT operators controlling the properties of the liquid metal just before pouring might be asked to take samples and temperature measurements more frequently, which might be perceived as an intensification of work (to take a measurement, operators have to leave their control booth and put on protective clothing). At the same time, some of their current tasks, e.g. manually inputting temperature data into a data base, might be automatised and thus reduce tasks to be performed. *Our idea is, for example, a thermal analysis to integrate all information in our SAP system to avoid manual interaction...All information automatic' (FDT11).*
Impact on Privacy	As no personal data are utilised or generated by the ALCHIMIA system, it is likely to have no impact on privacy. Moreover, 'surveillance' of work processes is already an established practice in the participating companies. Companies already know which specific member of staff has been involved in which activity when. *It's a bigger tool, but it's a long time that we are working with data... I think that there won't be a change or fearing that regarding AI because we already work like this here (CELS4).* Cybersecurity is another important aspect with potential consequences for privacy in the sense of business confidentiality but also to ensure that ALCHIMIA can work in the long-term. If malign actors were able to access the system, they could not only gain access to confidential production process data but also, in the worst case, manipulate data or insert fake data that would adversely affect the capabilities of ALCHIMIA. *[Cyber security] is something that we should consider... [Using ALCHIMIA means] that you let someone inside your network and you have to control this. Of the most preoccupations of Celsa group is not to have our data go out and spreading everywhere to the other companies*

Acceptance Factors	Issues
	and so on because our company knows that what the technology could do and how easy it can be spreading information everywhere. It's something that should be very [carefully] considered in terms of the project management, because if we are not dealing well with all of our aspects in IT, cybersecurity, data management and so on, I think it could make the projects run slowly' (CELF8)
Impact on Agency and Control	ALCHIMIA is likely to reduce agency and control in some specific areas. In both of the use contexts, ALCHIMIA aims to holistically optimise processes. This means ALCHIMIA is capable of making decisions affecting tasks and whole processes that are currently taken by operators. The most affected area in both use cases appears to be the furnace control which steers the melting process, which is currently heavily dependent on the expertise and experience of operators and engineers. If ALCHIMIA were to automate decisions, the short-term risk is that work becomes duller as operators just need to oversee an automated process. In the long run, there is a considerable risk of de-skilling: *So, you are offering to me a system [ALCHIMIA] that provides us with continuous forecasts, and we try to follow along with that. On one side, it diminishes firm's know-how and depletes employees who are supposed to grow [in terms of knowledge acquisition]. When you use this system, you are given pre-digested information. So, you don't have to make any sort of effort to understand it…to understand how you got there. (FDT1)* To minimise adverse impacts on agency, control and competences of operators, ALCHIMIA is designed to provide decision-support instead of automating decision-making, which leaves operators still in overall control and they can decide whether to follow ALCHIMIA's suggestions or not.
Impact on Job Security	Observations and interviews suggest that ALCHIMIA is unlikely to lead to job losses. The main reason is that efficiency gains are to be realised through process optimisation and not through a fundamental reconfiguration of these processes which might lead to a reduction of the workforce. In fact, implementing and using the ALCHIMIA system is likely to have positive effects on job security in the participating companies. On the on the hand, the efficiency gains should improve the competitiveness of the plants, thereby safeguarding existing jobs. On the other hand, new jobs might have to be created to support the implementation and running of the ALCHIMIA system. *No, I don't think workers can be replaced by the system; certainly not at the production level. At the follow-up level, you could reduce a series of checks, make them less frequent, but still, you have to do them. So, I'm*

Acceptance Factors	Issues
	having a hard time seeing where it can physically be reduced the number of people, as checks still need to be done… They will not get rid of hourly check, hourly control, because it's mandatory and obligatory (FDT1).
Impact on Employment Relations	The social research has not (yet) found any evidence that employment relations are likely to be adversely affected. Survey results but also interactions with staff during site visits suggest that ALCHIMIA is largely seen as a desirable and necessary technological development that should safeguard jobs through increased competitiveness and reduced environmental impacts. *It's not really [a threat to jobs], because I think this project is something to optimise costs, more or less our optimising to reduce emissions and so it's not directly part of some jobs. They are not looking to reduce jobs for people, they are looking for optimization of emissions, cost and so on. At the end, an operator that is working on the electrical arc furnace, this job will not be so different if you produce at low cost or with a big cost. (CELF8).*
Impact on OHS	Given that the anticipated impacts on tasks and jobs of ALCHIMIA are likely to be very limited, the likely impact on occupational health and safety is also limited. The increased frequency of manual measurements in one of the participating companies means that up to two operators per shift will be more frequently operating in the immediate proximity of liquid metal, but operators wear safety equipment, and the hot liquid metal is contained in a narrow channel connecting ladle furnaces and moulds.

Beyond the rather general social requirement of 'user acceptance', the social research, based on interviews and *in situ* observations, has also identified two more specific social requirements that ALCHIMIA users are already paying attention to.

4.6.2 Automating data input into data bases

Accuracy and reliability of measurements that provide data relied on by the ALCHIMIA system are crucial for the AI system to function as intended. Given that hot and often liquid metal, which is handled in all participating plants, is very dangerous to work with, automation and remote controlling of processes is very advanced. This means almost all production-related data relevant for ALCHIMIA is measured automatically and, equally as important, is fed automatically into the relevant data bases held by the companies. Currently there is one exception in the FDT plant producing car parts. At the stage when liquid metal is poured into moulds (see Table 2 above), operators overseeing the pouring process are required to take a temperature measurement as well as a small physical sample of the liquid metal just before it reaches the mould every 30 minutes. The operator inserts a thermometer into the stream of liquid metal and the temperature then appears on a large display in the control boot. Crucially, however, the temperature measurement is not fed into any databases automatically. Instead, one task for operators is to enter the temperature reading manually into a computer and only then is it stored in the FDT database.

It is very likely that in the majority of cases, this manual transfer of temperature data from display into the IT system of the company works as intended. There are, however, two sources for error that can adversely affect the data held by FDT. One source of error is when operators forget to take a sample at the required time. This happens relatively rarely despite the fact that there are currently no prompts or reminders in place (e.g. a automated alarm going off every 30 min or a reminder popping up on the control screen) to nudge the operator to do the measurement. Another source for potential error is the manual transferal of data from display into the IT system. Again, mistakes appear to be rare but the risk of a wrong entry exists.

FDT is already acutely aware of this and is committed to solving these issues so that all data measurements taken in the plant are automatically fed into the databases. Automating measurements might also allow the company to increase the frequency of measurements, which improves the data basis upon which ALCHIMIA is trying to optimise production:

> *'Yes [we are planning to maybe increase the frequency of the measurements], because today the mechanical resistance is made one time each batch, but in our opinion, for machine learning, the instrument, is necessary to have the same sampling, one each hour because in this way all information are connected. (FDT11).*

4.6.3 Additional capacity and competence needs

Based on our research, there are at least three areas or issues related to additional capacity and competence needs to which users of ALCHIMIA have to pay attention. First, companies need to account and plan for additional training time of their workforce. While ALCHIMIA is working in the background and thus affecting workers and tasks in relatively minor ways, additional training needs around understanding, interacting and using AI-based production support systems such as ALCHIMIA are required to ensure ALCHIMIA can run smoothly in future. As both participating companies operate with poly-valent jobs descriptions, which means that instead of mono-tasking operators are capable and expected to perform a wide range of tasks in their area of deployment, training will have to cover most if not all of the production-related workforce.[15]

Second, optimising tasks and processes through technology, e.g. through automation, use of AI or robotics and so on, is also likely to create new requirements with regard to competences and expertise of their workforce.[16] Some of these new requirements can be

[15] For example, the teams operating EAF furnaces consist of 4 to 6 operators. An operating ALCHIMIA system would affect the tasks of just one or two operators who are in charge of controlling the melting process. Due to poly-valance, any of the furnace team members might control the melting process, which means all team members require training to successfully work with ALCHIMIA.

[16] In Germany, for example, this has led to an initiative of the Federal Institute for Vocational and Educational Training (BIBB), which is largely responsible for vocational and educational training in Germany, called *Berufsbildung 4.0* (literally 'Occupational Training 4.0). This initiatives systematically reviews all occupational qualification programmes to make them fit for the changing demands due to Industry 4.0 (https://www.bibb.de/de/26729.php).

identified already at this early stage of the development of ALCHIMIA while others will emerge at a later stage. Interviews conducted in the participating plants suggested that participating companies have identified a range of potential new tasks or jobs that is likely to require recruiting additional staff with new or additional competences and expertise. Interviewees mentioned AI-related expertise, additional and new IT competences, competences related to data analysis and additional or new maintenance capabilities.

> *"Now we are focusing attention on basically on knowledge about artificial intelligence, data management, data engineers and data scientists. So, we think that in the near future we will need more of this... And also, for the technical engineers... they require new skills related with artificial intelligence, data management, all these issues...more and more we require people who are more familiar on how to analyse the big amount of data... maybe some data scientist in the company or some engineers that are able to understand what a data scientist says...of course the process engineers won't be the expert from data scientist, but they need to have which are the results and the conclusions, et cetera and these require some skills about that OK". (CELS7).*

Companies have some flexibility as to how they approach such competence gaps: they can create new job profiles and hire qualified staff or they can up- or re-skill existing staff or buy-in external expertise according to their needs.

5 Human-Centred Design Recommendations

5.1 Introduction

This section of the report consists of three parts. An introduction provides some background on concepts and standards that inform the more analytical parts of this section. Specifically, the concept of *Human-Centred Design* (HCD). The second part focuses on 'insights' into the ALCHIMIA project. It describes and analyses with the help of the HCD concepts whether the technology design and development process is aligned with and adhering to the principles of HCD. The third part builds on the previous part and develops recommendations as to how adherence to and alignment with the principles of both HCD can be sustained and, where required, be improved in the ALCHIMIA project.

5.2 Human-Centred Design

The ALCHIMIA project's approach to human-centred is guided by ISO 9241-110: 2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems (International Organization for Standardization 2019). The standard defines the approach, establishes principles and suggests a process designed to ensure designs are human-centred. In this section, we will briefly introduce the concept of HCD and then use the principles and the process steps as set out by the ISO standard as benchmarks to analyse to what degree the ALCHIMIA process has adhered to the prescriptions.

ISO 9241-110 defines human-centred design as an 'approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques' (International Organization for Standardization 2019: Section 3.7).

The standard also sets out 6 principles that characterise design processes that are supposed to be human-centred.

1. The design team includes multi-disciplinary skills and perspectives
2. The design is based upon an explicit understanding of users, tasks, and environments.
3. The process is iterative.
4. The design is driven and refined by user-centred evaluation.
5. The design addresses the whole user experience.
6. Users are involved throughout design and development

To achieve human-centred designs, the ISO standard suggests a 4-step process. Surveying other contributions to the literature around HCD, there appears to be a strong consensus that a four-step process appears to be best, even though alternative approaches use alternative terminology.

Table 25: Overview of different HCD Process Definitions

Step	ISO 9241-110	Harvard Business School[17]	Lienig & Bruemmer (2017)
1.	Understanding and specifying the context of use	Clarify	Task definition (informative definition)
2.	Specifying the user (and organisational) requirements	Ideate	Conceptual stage (cardinal definition)
3.	Producing design solutions	Develop	Design stage (formative definition)
4.	Evaluating the design	Implement	Implementation stage (manufacturing definition)

5.3 Insights

In this section, the report briefly analyses the extent to which the ALCHIMIA design has aligned itself to the HCD principles and the procedural prescriptions as set out by ISO9241:110. With regard to the process, this report reflects the efforts made during the first two of the four process stages, which were the focus of T2.1 and T2.3. A schematic summary of the analysis is presented in Table 3, which effectively represents a HCD Matrix. The coloured dots indicate to what degree the ALCHIMIA project is adhering to HCD principles during the first two process steps. Overall, we assess that the project is well aligned with HCD principles although there is room for improvement with regard to two of the six principles.

[17] https://online.hbs.edu/blog/post/what-is-human-centered-design

Table 26: HCD Matrix[18]

	The design team includes multi-disciplinary skills and perspectives	Users are involved throughout design and development	The process is iterative	The design is driven and refined by user-centred evaluation	The design is based upon an explicit under-standing of users, tasks, and environments	The design addresses the whole user experience
Understanding and specifying the context of use	Green	Green	Yellow/green	Yellow/green	Green	Green
Specifying user requirements	Green	Green	Yellow/green	Yellow/green	Green	Green
Producing design solutions						
Evaluating the design						

In the following sub-sections we provide a more detailed narrative of the analysis. This will be structured by considering HCD Principles in turn.

5.3.1 HCD Principles 1 and 2

We can consider the first two HCD principles together because the alignment of the ALCHIMIA project with them is effectively guaranteed through the make up of the research team. The consortium approach to large research projects utilised in the context of Horizon (and other European funding schemes) ensures that multi-disciplinary skills and perspectives (**HCD Principle 1**) are built into research processes. The ALCHIMIA partners involved in the design process can draw on a wide spectrum of academic and professional expertise that help to understand and specify then contexts of use for the ALCHIMIA system from a wide range of angles and perspectives (see F. The team comprises metallurgists, engineers, data scientists, IT specialists, modelers and social scientists). Moreover, some of the key research team members are also prospective stakeholders in and users of the ALCHIMIA system.

[18] Green indicates full alignment with and adherence to HCD principles, yellow indicates medium (or patchy) alignment with and adherence to HCD principles and red indicates no alignment with and adherence to HCD principles. Given that iteration and user-centred evaluation have played significant roles but could have been more intense and frequent, we use a mix of yellow and green to indicate that alignment with and adherence to HCD has not been complete but more than patchy.

Table 27: Multi-Disciplinarity and complementarity of competences of ALCHIMIA consortium

Competences	Atos	SSSA	BFI…	CAR	CEL	EXUS	MI	FDT
Big Data	✓	✓	✓			✓	✓	
Federated Learning	✓		✓			✓		
Transfer Learning	✓		✓			✓		
Modelling	✓	✓	✓		✓	✓		✓
Optimisation		✓	✓		✓			✓
LCA		✓			✓		✓	✓
Trustworthy and explainable AI	✓		✓	✓		✓	✓	
IIoT / monitoring	✓	✓	✓		✓	✓	✓	✓
Industrial use-cases					✓			✓
SSH				✓	✓		✓	✓
Environmental impact assessment		✓			✓		✓	✓

Given that the initial users and some of the key stakeholders of the ALCHIMIA system are members of the ALCHIMIA consortium, user as well as stakeholder involvement throughout design and development (**HCD Principle 2**) is built into the project design and thus guaranteed. In the case of the proposed ALCHIMIA system, which affects large and complex production systems, it is not practically possible to involve each and every prospective user (and stakeholder) to the same degree throughout all stages of the design process.

5.3.2 HCD Principles 3 and 4

While HCD Principles 1 and 2 benefit directly from the organisational structure of the research consortium, the same is not necessarily true for 'iteration' (**HCD Principle 3**) and 'user-centred evaluation that is driving the design and implementation process (**HCD Principle 4**). The multi-disciplinary consortium structure that involves users and stakeholders alike provides the opportunity for iteration and user-centred evaluation, but does not guarantee it. Indeed, it is with regard to these two principles that the current ALCHIMIA development process has some deficits. Iteration and user-centred evaluation have of course played an important role so far: for example, the Use Case Forms have been iteratively completed by the participating companies and technically oriented consortium partners as several versions of the documents have been produced. The same has been true for many other aspects of technical development where iterations played a central part in making concrete progress.

These iterative development processes also involve user-centred evaluation of design insofar as it allows for a dialogue between users and developers that helps to bridge potential incompatibilities between what is desired by users and what developers believe to be technically feasible. Under ideal circumstances, these structured exchanges would have been more structured, frequent and intense with the clear aim to arrive at a state of mutual satisfaction at a defined point in time. To some extent, the consortium structure of the ALCHIMIA project proved to be a barrier as partners are dispersed across Europe, language barriers exist and capacity within partner organisations to afford more exchange and cooperation is limited – both in terms of financial resources and time.

5.3.3 HCD Principles 5 and 6

In order to base the ALCHIMIA design on an explicit understanding of users, tasks and environments and to take the whole user experience into account, the team has utilised a range of tools and methods to gain user-centred perspectives. These tools were:

Table 28: Tools utilised to gain user-centred perspectives

Tools	Description
Consortium meetings involving both users and developers	• Regular Task Group Meetings: to deal with specific issues related to specific tasks • Regular Work Package meetings: to coordinate activities across a Work Package • Ad-hoc and regular Technical Meetings: started already at project proposal development stage and continued throughout first 12 month of project (sometimes directly involved users (operators or company IT managers) who were not members of the research team); some of these meetings have been combined with plant visits to allow additional in-situ observations of processes
Cloud-based Collaboration Platform, accessible by all consortium partners	Affords sharing and working collaboratively on relevant documents
GitHub repository for technical collaboration	Affords sharing and working collaboratively on technical design and development of ALCHIMIA platform
Use Case Forms (based on IEC 62559)	Completed by participating companies with assistance from technical ALCHIMIA partners
Semi-structured interviews	• Always combined with plant visit so that researchers were able to observe and understand project-relevant processes, tasks and behaviours as well as the wider operational context • Whenever possible, interviews were conducted *in situ* to allow direct observations of project-relevant behaviours, tasks and processes as well as to gain insights into user views on technology development (user experience)

Tools	Description
Surveys	• Short standardised survey to designed to gain insights into users (1) understanding of, (2) involvement in, (3) attitudes to and (4) opinions about ALCHIMIA. • Voluntary participation translated into modest response rate

With regard to HCD Principle 5, it has not been practically possible to engage with all potential users of the proposed ALCHIMIA system. One significant barrier is that the project idea has to be at a relatively developed stage before funding is granted which limits opportunities for wide-spread engagement of potential users. This means that at the crucial framing stage of the project, only a relative small number of users, usually working in positions with managerial responsibilities, has been actively involved. The social research component has allowed the consortium to widen engagement with users significantly even though the numbers are still relatively small compared with the number of potential users in the participating plants. User engagement was necessarily limited due to time and resource constraints which only allowed for a two-day visit including plant tour in each of the four participating plants. Using semi-structured interviews that lasted between 30 minutes and 2 hours has, however, allowed the research team to gain good insights into task and processes and the ways in which users engage with these during work.

Sustained technically focused discussions that involved users (see above) as well as in-depth social research using interviews and methods has allowed the project to acquire a good understanding of the whole user experience. User experience has in the past often been reduced to considerations about user interfaces and their usability. User experiences are, however, multi-dimensional. According to Peter Morville, an expert in information architecture, at least seven dimensions can be distinguished (see Figure 3) and design processes should pay attention to all of them.[19]

[19] https://semanticstudios.com/user_experience_design/

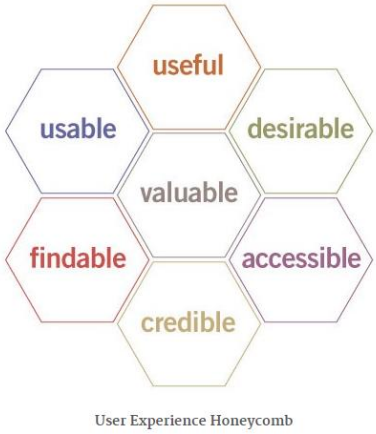

Figure 3: Dimensions of user experience according to Morville

While not all of these dimensions are equally relevant in the context of the ALCHIMIA project – for example the 'findability' of information on a screen or an interface – paying attention to more than usability encourage designers to ask questions such as: Is a system useful to users/ stakeholders? How easy is to use the system? How attractive or desirable is the use of the system? How easy is it to find or retrieve information? How accessible is the system to all kinds of prospective users, including disabled people? How trustworthy is the system? How valuable is the system to different users and stakeholders?

ALCHIMIA's holistic approach to understanding users, tasks and contexts of use that pays attention to technical and social aspects of use as well as the alignment of the project with EU Guidelines on Ethical and Trustworthy AI (see section on Foresights) ensures that concerns for user experience go well beyond questions on user interfaces and ease of use.

5.4 Foresights

5.4.1 ALCHIMIA-specific recommendations

In general, the analysis of the extent to which the ALCHIMIA project adheres to the HCD principles suggests good levels of alignment, which should be sustained during the remainder of the project. The fact that the ALCHIMIA system is to be developed by an international consortium has complicated alignment with HCD principles. Wide geographical dispersion of the research team in conjunction with limited resources create structural barriers that make user and stakeholder engagement and completing iterative processes difficult.

Despite some structural barriers that are difficult to overcome, we identify three issues that appear to be achievable and that should further strengthen and improve the alignment of the ALCHIMIA project with HCD principles.

Table 29: ALCHIMIA-specific recommendations

Recommendation	Description
More structured, frequent and intense communication	HCD principles emphasise the importance of continuous user and stakeholder input into the design, development and ultimately implementation of a new technology. Continuous feedback loops are important to incorporate user/ stakeholder views and to

Recommendation	Description
and collaboration between users, stakeholders/ developers	prevent misunderstandings from affecting the technological design. Two factors seem influential in adversely affecting the frequency and intensity of communication: 1. the geographical dispersion and 2. the occupational diversity of the involved actors. Geographical dispersion, i.e. the fact that users and stakeholders are located in different countries across Europe makes face-to-face meetings costly and time-intensive although these factors can, in principle, be partly mitigated by using remote communication channels such video-conferencing or emailing. In conjunction with occupational diversity, i.e. the fact that ALCHIMIA users and stakeholders comprise a diverse set of actors, including shift-working operators, academic researchers and engineering consultants, even remote communication becomes difficult as available capacity and time to engage in communication is very limited for some of these actors. Particularly problematic is the difficulty for finding mutually suitable times slots for meetings, which makes it almost impossible to organise ad-hoc or urgent meetings that might sometimes be required to respond to an emergent issue. Given the necessity for frequent and intense communication between users and stakeholders as part of the HCD-led ALCHIMIA development process, we recommend that communication efforts are better planned and structured. To some extent this is already practiced within the ALCHIMIA project as certain aspects of communication and collaboration follow a pre-determined plan. For example, there are monthly consortium tele-conferences and six-monthly in-person consortium meetings that every partner knows about well in advance. We suggest that all meetings at work-package and task level are pre-scheduled in regular and frequent intervals on days and times that suit all involved actors. If it is recognised that a meeting is not required, it can be cancelled. Such an approach should solve the problem that mutually suitable meetings times are hard to find, especially in a short time-frame as it is much easier to cancel an already scheduled meeting than to organise one.
More general information for workers within plants	While the collected survey responses indicate that those who completed the surveys had a fairly good understanding of ALCHIMIA, it is possible that those who do not know much about ALCHIMIA did not feel compelled to engage with the survey. This at least is one plausible explanation for the low response rate. As the previous section has shown, user acceptance is an important factor in ensuring that new technologies can work as intended. Ensuring that workers have a clear and honest explanation as to why a new technology is needed and what the likely consequences for the company and their jobs are, is therefore an important and essential component of technology development, notwithstanding whether HCD principles are explicitly embraced or not.

Recommendation	Description
	An important issue to be dealt with by the ALCHIMIA project in the next stage that demands high and intense user engagement will be the design of interfaces that allow users to control the ALCHIMIA system. We recommend the use of highly interactive fora to allow prospective users of the ALCHIMIA system influence the design of such interfaces to ensure that they meet user needs. Which exact form these interactive fora take, e.g. dedicated working groups or focus groups or staff assemblies, depends on the local contexts and preferences. The important aspect is that they afford users the opportunity to meaningfully influence the design of interfaces.
More interdisciplinary working between the social science and technical partners	The multi-disciplinarity of the ALCHIMIA consortium is generally a strength, but also creates the risks of disconnections between project partners due to different expertises and methods of working. The most obvious disconnect between expertises is between technical and social aspects of the project. As the report shows, both sets of expertises are important to ensure a newly developed technology can work as intended. There are, however, also important expertise gaps between 'technicians' that must not be overlooked: data scientists and IT specialists tasked with the technical realisation of ALCHIMIA do not necessarily understand the intricacies of the production processes that they are helping to model. Bridging expertise gaps is inherently difficult and time-intensive but not impossible when pragmatically handled. Social researchers, for example, do not have to become deep experts in Machine Learning or algorithms, but they need to acquire some understanding of technical aspects to understand whether technicalities have consequences for social aspects and vice versa and also, importantly, to be able to communicate effectively with colleagues operating in different expert domains.[20] Likewise, programmers and IT specialists do not need to turn into social scientists or metallurgists to understand human factors or industrial steel-making processes. The different expertise gap within the ALCHIMIA team can be, to some extent, reduced through increased frequency and intensity of active communication. There are limits to what is possible, partly due to the dislocation of partners and limited resources. But even

[20] Collins and Evans (2007) distinguish contributory expertise – which allows one to actively practice and contribute within a specialist field – and interactional expertise – which allows non-specialist to communicate with contributory experts about a specialist subject. While the former can take years and sometimes decades to acquire, the latter is much easier and faster to pick up. We suggest that partners in ALCHIMIA ought to develop interactional expertise in those disciplines and fields involved in the project in which they are not contributory experts.

Recommendation	Description
	if it might not be possible to increase the frequency of communication, existing opportunities for exchanges between partners can be improved through more engaged communication efforts. An important element is for partners to demonstrate the will to understand (conceptually at least) what others do and why they do what they do.

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Appendix A System Requirements

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.01	Users authentication	The platform should provide a mechanism for users to authenticate themselves before accessing the system, such as username/password, two-factor authentication, or OAuth.	Users / organisations System administrators	ATOS	MUST	Users can create a new account with a unique username and password. Users can log in with their username and password. Users can reset their password if they forget it. The system enforces password complexity rules (e.g., minimum length, special characters).
FR.02	Users management	The platform should provide a mechanism for managing users, such as adding, deleting, or modifying user accounts, assigning roles and permissions, and managing user preferences.	Organisations System administrators	ATOS	MUST	Organizations can create and manage user accounts within their own organization. Users can view and edit their own profile information (e.g., name, email address, contact information). Administrators can view and edit user profiles for users within their organization. The system enforces role-based access control (e.g., administrator, user, guest).

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.03	Organization management	The platform should provide a mechanism for managing organizations, such as creating, deleting, or modifying organization accounts, assigning roles and permissions, and managing organization preferences.	System administrators	ATOS	MUST	Administrators can create and manage organization accounts. Administrators can assign users to organizations. Administrators can view and edit organization profile information (e.g., name, description, contact information).
FR.04	Access control	The platform should provide a mechanism for controlling access to data and models based on user roles and permissions, such as read-only access, read-write access, or admin access.	System administrators	ATOS	MUST	The system enforces role-based access control Users can only information for which they have been granted permission. Administrators can manage access control policies for their organization's resources.

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.05	User activity monitoring	The platform should provide a mechanism for monitoring user activity within the system, such as login/logout events, data access events, and model training events.	System administrators	ATOS	COULD	The system can log the following user activity events The system can associate each event with a unique identifier for the user or resource in question The system can provide a user interface for viewing logs, generating reports, and searching for specific events The system can generate alerts and notifications for critical events, such as security breaches or system downtime
FR.06	User privacy	The platform should ensure the privacy of user data, such as personal information, activity logs, and communication logs.	System administrators	ATOS	MUST	The system uses encryption and other security measures to protect sensitive data in transit and at rest.

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.07	Multi-tenancy	The platform should support multiple tenants, such as different organizations or departments, with their own data and models.	System administrators	ATOS	SHOULD	The system can support multiple tenants, each with their own data and models. The system enforces tenant isolation and ensures that data and models from one tenant cannot be accessed or modified by another tenant. The system provides a mechanism for administrators to create, manage, and delete tenants. The system allows users to be assigned to one or more tenants, and enforces access control policies based on tenant membership The system can aggregate model updates from multiple tenants, and ensure that models are only deployed to the tenant for which they were trained.

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.08	Federated Learning task creation	The platform should provide a mechanism to register a new Federated Learning task, providing detailed information about it (e.g., data sources, the participating organizations, the machine learning model to be trained, and the training protocol to be used)	Data scientist	ATOS	MUST	The system can provide a user interface for registering a new Federated Learning task, and require users to provide detailed information about the task. The system can validate the input parameters and ensure that all required fields are provided. The system can store the task information in a secure and scalable format, such as a distributed database. The system can assign a unique identifier to the task, and use it to track the task's progress throughout its lifecycle.

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.09	Federated Learning task management	The platform should provide a mechanism to visualise, modify and cancel Federated Learning tasks.	Data scientist	ATOS	MUST	The system can provide a user interface for visualizing, modifying, and cancelling tasks. The system can display a list of registered tasks, along with their current status, progress, and metadata. The system can allow users to filter, search, and sort the task list based on various criteria. The system can allow users to click on a task to view its detailed information, such as the participating organizations, the data schema, and the learning objective. The system can allow users to modify the task information, such as adding or removing organizations, changing the training protocol, or updating the metadata. The system can validate the modified task information and ensure that it is compatible with the existing data and models. The system can allow users to cancel a task at any time, and ensure that the task's resources are properly released and cleaned up

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.10	Join Federated Learning task	Participants should have the possibility to visualise open FL tasks in their tenant and to join it.	Data scientist	ATOS	MUST	The system can provide a user interface for participants to discover and join open Federated Learning tasks in their tenant. The system can display a list of open tasks, along with their metadata, such as the data sources, the participating organizations, and the learning objective. The system can allow users to filter, search, and sort the task list based on various criteria, such as the task status or the task type. The system can provide a mechanism for users to express their interest in a task, such as by clicking on a "Join" button or by submitting a request form. The system can validate the user's eligibility and credentials before allowing them to join the task, such as by verifying their role, permissions, and authentication token. The system can notify the task owners or administrators of the user's interest and allow them to approve or reject the request.

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.11	Federated Learning models management	The platform should provide mechanisms to visualise and download resulting models	Data scientist	ATOS	MUST	The system can provide a user interface for visualizing and downloading the resulting models from Federated Learning tasks. The system can display a list of completed tasks and their trained models. The system can allow users to download the trained models, such as by clicking on a "Download" button or by selecting a format or version. The system can validate the user's eligibility and credentials before allowing them to download the models
FR.12	Aggregator must be able to store updates from participants	The Federated Learning platform must provide a mechanism for the aggregator to store the updates received from participants during the training process. The updates can include model weights, gradients, or other parameters that are computed locally on	Data scientist	ATOS	MUST	The updates can be stored in a database or other data storage system that supports efficient and flexible querying and retrieval of large volumes of data. The updates can be versioned, compressed, encrypted, or otherwise optimized for performance, privacy, and security. The updates can be associated with a task ID, a participant ID, and a timestamp, to enable

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
		each participant's device and sent to the aggregator for aggregation and refinement.				tracking, monitoring, and auditing of the training process. The updates storage can provide a user interface or API for querying, visualizing, and downloading the stored updates, subject to appropriate access controls and authentication mechanisms.
FR.13	Data privacy	Privacy must be ensured through techniques such as differential privacy, federated encrypted algorithms, and secure aggregation.	Data scientist	ATOS	MUST	The platform must implement differential privacy techniques to protect sensitive information and prevent re-identification attacks e platform must use federated encrypted algorithms to ensure that data is never transmitted in plaintext between devices or to the server. The encryption scheme should be secure, efficient, and compatible with various types of data The platform must use secure aggregation techniques to combine the model updates from different devices without revealing the

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
						individual updates or compromising the model's accuracy. The aggregation scheme should be robust, fault-tolerant, and resistant to collusion and adversarial attacks
FR.14	Model distribution	The Federated Learning platform must provide a mechanism for distributing the updated model from the server to the participating devices after each round of training	Data scientist	ATOS	MUST	The model distribution mechanism must be able to handle a large number of participating devices, up to the maximum capacity supported by the platform. The model distribution mechanism must ensure the integrity and confidentiality of the model during transmission and storage, using techniques such as encryption, hashing, and authentication. The model distribution mechanism must provide a high level of availability and reliability, with minimal downtime or errors, even in the

ID	Requirement description	Rationale	Required by	Proposed by	Priority	Acceptance criteria
Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
						presence of network disruptions or device failures. The model distribution mechanism must be configurable and adaptable, allowing users to choose the type of distribution mechanism that best suits their needs and preferences, and to adjust the parameters of the mechanism as needed.
FR.15	Model inference	The local participants must have the possibility for using the trained model to perform inference on new data	Data scientist	ATOS	MUST	The platform must allow participants to use the trained model to perform inference on their own data, either on their device or in a secure cloud environment. The platform must provide mechanisms for validating and verifying the quality and accuracy of the trained model The platform must provide mechanisms for monitoring and reporting the performance and usage of the model

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FR.16	Model monitoring	The platform should provide mechanisms for monitoring the performance and accuracy of the trained model over time, and for detecting and mitigating biases and fairness issues that may arise from the data or the learning process.	Data scientist	ATOS	SHOULD	The platform must support the collection and analysis of performance metrics and logs for the trained model The platform must provide mechanisms for visualizing and comparing the model's performance metrics over time
FR.17	Continual Learning	Depending on the metrics obtained with the monitoring of the model during the inference phase, a new retraining process will be triggered.	Data scientist	ATOS	SHOULD	
FR.18	Human feedback	The platform should provide mechanisms for incorporating human feedback into the federated learning process, using active learning techniques to improve the accuracy and	Operators	ATOS	SHOULD	The platform must support the integration of human feedback data into the federated learning process, allowing users to annotate or label data, provide feedback on model predictions, and update or correct existing labels as needed. The platform must support the training and

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		performance of the trained model.				evaluation of the model in an iterative and interactive manner, where the model is updated based on the human feedback The platform must provide feedback and guidance to the human experts on the quality and reliability of their feedback
FR.19	Explainability	The platform should incorporate features to facilitate understanding the results produced by the models during the inference phase, such as generating reports, visualizations, and summaries that provide insight into the model's behaviour and performance.	Operators	ATOS	SHOULD	The platform should generate reports that provide detailed information about the model's behaviour during the inference phase, such as accuracy, precision, recall, and F1 score. The platform should provide visualizations that help users understand the model's performance, such as confusion matrices, ROC curves, and precision-recall curves. The platform should generate summaries that provide a high-level overview of the model's behaviour and performance, such as identifying trends and patterns in the data.

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FR.20	Scrap characterization	One service should be able to characterize scrap in terms of composition, meltdown energy requirements and environmental aspects by means of statistical or first-principal methods based on historical data. Such characterization could facilitate the generalisation of the problems to be solved in ALCHIMIA and enable the utilization of Federated Learning.	Operators	BFI + CELSA	MUST	Service reads historical data and performs characterization (e.g., via linear regression). Required data includes steel analysis, scrap inputs, tapping weight, aggregated EAF operation information, environmental data (SSSA). Service should provide results on uncertainties in scrap properties and statistics on accuracy. Service should be able to depict temporal trends, include functions to export the results and filter heats.
FR.21	Steel quality prediction	One service should be able to predict resulting raw steel properties based on material and aggregated process operation input. Service should be compatible with FL and optimization framework.	Operators	BFI + CELSA	MUST	More specific use case of FL platform, should exploit functionalities provided by the platform

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Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.22	Scrap mix optimization	Service for production planning, should provide optimal scrap mix and operating recipes under given boundary conditions and optimisation targets	Operators	BFI + CELSA	MUST	Input of boundary conditions and production schedule via UI or API. Visualization of optimal scrap mix and operating recipes as well as predicted steel quality and associated costs/environmental impact
FR.23	Dynamic Process Model EAF for Monitoring	Service for online monitoring of EAF process. Should provide real-time information on steel properties in EAF process.	Operators	BFI + CELSA	MUST	User can observe the current EAF process state in real-time via UI and analyse results from historical heats
FR.24	Dynamic Process Model EAF for Predictive Control Suggestions	Service for real-time set-point suggestions in EAF process based on predictions provided by underlying process model and given optimisation targets. (Dynamic control).	Operators	BFI + CELSA	MUST	User can observe control suggestions and predicted impact on the EAF process

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Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.25	Optimization task creation	The user should have the possibility to set different parameters of the optimization problems and solvers.	Optimization expert	SSSA	MUST	The system must provide a user interface for set up the bounds (e.g. min, max, ranges, etc.) of the main process constraints. The system must provide a user interface for set up the main parameters of optimization solvers. The system must provide a user interface for set up the prices of the objective function terms. The platform must support the collection, visualization and analysis of logs of the calculated optimization strategy.
FR.26	Visualization of optimization strategy, optimization results and performance metrics.	The system must provide real-time monitoring and visualization of optimization strategy, optimization results and performance metrics, comparing them with the actual process and product parameters to allow process operators to make necessary	Operators + Data Scientist	SSSA + CELSA + BFI	MUST	The system must have a user interface that can display the results of optimization tasks through numerical and/or graphical means, including information on the quality of the optimization strategy. The visualization of expected and real performance should be available at any time and recorded. The interface must allow for the comparison of optimization suggestions with

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		decisions for optimizing the steel recipe in each of its production processes.				actual results, highlighting key variables and aiding in decision making.
FR.27	Scrap inventory	All main information about scraps coming both from plants data and from models must be available to the operators. Some examples are the programs for scrap purchasing, expected processing, available scraps as well as all main info regarding scraps features, their impact on the process and on the sustainability, on resources consumption and on the product quality and composition. Visualization features need to highlight best and worst scraps (considering	Operators	SSSA + CELSA	MUST	An interface must be linked both with scrap data and with models for scrap inventory in order to allow the workers easily understanding the types of available scraps and why they are chosen by the optimizer.

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		the aspects listed before), more available and less available scraps, etc. 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 obtained				
FR.28	Models and simulation managing	Model configuration, launch and visualization of results must be ensured. Especially for real-time/semi-real time models, accuracy needs to be monitored and retraining/retuning needs should be visualized. While for models allowing only offline	Operators and Model experts	SSSA	MUST	The system must have an interface for selecting, managing models and simulations considering all their functionalities.

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		scenario analyses (e.g. scrap processing models) an interface to configure the scenario to be analysed, to set sensitivity analyses and to execute model also once must be ensured. Models updating must be ensured. Reset of default model parameters should be included.				
FR.29	LCA service	A service must be ensured to make LCA and visualize results	Operators	SSSA	MUST	An interface must be linked with LCA tool to allow its usage and the visualization of results.
FR.30	Export model definitions	Exporting current status and configuration of a model simulation to be reproduced later or in a different ALCHIMIA system installation	Operators, System Administrator	SSSA	SHOULD	A model export service.
FR.31	Interactive data visualization	Adjusting data/results visualization to the necessities of the user and performing basic transformations to the data for	Operators	SSSA	SHOULD	The system should have interactive visualisation capabilities where the main actor will be able to add variables to the plot, compare variables, adjust axis and scales,

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		better comparison and comprehension				perform regressions and statistical analysis of the visualised data in an interactive way. It should be possible to adjust aspect of the figures, colour scales and other aspects of the visual data interactively.
FR.32	Data acquisition	The service should be able to connect to various end points like Rest API, MQTT broker and acquire data from these endpoints.	System components	EXUS	MUST	The service should connect to the agreed provided endpoints and receive the agreed type, structure and volume of data.
FR.33	Data pre-processing and transformation	The service should be able to apply the predefined transformations to the incoming data.	System components	EXUS	MUST	The service should perform the predefined transformations, provided by the partners, to the data in order to bring them in the appropriate structure for storage.
FR.34	Data fusion and storage	The service should store the curated data to a database to make them available to the model training system components.	System components	EXUS	MUST	The service will store the curated data to a provided database so that can be available to the other system components for model training.

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Unique identifier	A description of the requirement	Why is it needed?	Stakeholder addressed by this requirement	Stakeholder that provided the requirement	MoSCoW (Must have, should have, could have, won't have).	Set of requirements that must be met to mark a user story complete
FR.35	Iron quality prediction	One service should be able to predict resulting raw iron properties based on material and aggregated process operation input. Service should be compatible with FL and optimization framework.	Operators		MUST	More specific use case of FL platform, should exploit functionalities provided by the platform
FR.36	Energy/ resources prediction	According to the Scrap characteristics (quality and quantity) and the steel grade to produce (Production planning), the model will determine the energy consumptions for a scrap mix chosen. The visualization of the results will appear in a specific interface.	Operators		MUST	
FR.37	Scrap processing		Operators		MUST	

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FR.38	Product quality prediction		Operators		MUST	

Appendix B Stakeholder/user-engagement Matrix

Project Arm	Actor	Description	Contribution to Requirements Definition via:					
			Project Design	System Require-ments Definition Process	Technical visits	Use Case Form Process	Social Research	ALTAI
CELSA	Celsa Group	Holding	X	X			X	
	Celsa France	Company			X	X	X	
	Celsa Spain	Company			X		X	
	Celsa Poland	Company					X	
	Melt Shop Head	Overall responsibility for steel mill					X	
	Scrap Yard Manager	Overall responsibility for Scrap Yard					X	
	Scrap Engineers	Scrap Yard Management					X	
	Scrap Sorters	Scrap Identification					X	
	Scrap Crane Operator	Responsible for Basket Charging						
	Electric Oven Charge							
	Production Manager	Responsibility for steel production (includes recipe selection)					X	
	Process Engineer	Responsibility for production process (design and maintenance)					X	
	Furnace Manager	Responsible for operating EAF						
	Melting Team Leader							
	Furnace Supervisor							

Project Arm	Actor	Description	Contribution to Requirements Definition via:					
			Project Design	System Require-ments Definition Process	Technical visits	Use Case Form Process	Social Research	ALTAI
	IT Manager	Responsible for IT infrastructure and data					X	
	Innovation Manager						X	
FDT	EF Group	Holding						
	FdT	Company	X	X	X	X	X	
	Production Manager						X	
	Furnace Manager						X	
	Furnace Operators						X	
	Casting Manager						X	
	Casting Operators						X	
	Laboratory assistants						X	
	Hourly Control Team Leader						X	
	Hourly Control Operators						X	
	IT Manager						X	
	Innovation Manager	Responsible for project implementation					X	
Partners	ATOS		X	X	X			
	BFI		X	X	X			
	SSSA		X	X	X			
	EXUS		X	X	X			
	MI		X					

Project Arm	Actor	Description	Contribution to Requirements Definition via:					
			Project Design	System Require-ments Definition Process	Technical visits	Use Case Form Process	Social Research	ALTAI
	CAR		X					
Others	EU/EC/ERC ?							

Appendix C Overview of interviewees and fieldwork dates

Company	Interviews
Celsa Poland (n=8) May 24th-25th 2023	Production Head General Manager of Production Scrapyard Manager Scrap Administrative Officer Circularity Manager HR Manager HR Officer x2
Celsa Spain (n=8) June 27th-28th 2023	Production Manager x2 Melt Shop Head Process Engineer Operator Scrapyard Manager Scrap Purchasing HR Officer
Celsa France (n=12) June 5th-6th 2023	Production Manager Melt Shop Head Melt Shop Manager Production Planner Scrapyard Head Scrapyard Manager Finance Head Scrap Purchasing x2 Process Engineer

Company	Interviews
	HR Manager IT Manager
FDT (n=18) May 16th-17th 2023	Head of Production Melt Shop Head Melt Shop Coordinator Melt Shop Operator x3 Casting Operator Technical officer Manager of Metallurgical Laboratory Metallurgical Laboratory Technician x3 Shift Leader Testing Testing Officer x3 HR Manager IT Manager