smart retrofitting in process industry

Project acronym: RETROFEED
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Document sheet

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2 EXECUTIVE SUMMARY

RETROFEED (www.retrofeed.eu) is a European funded project aiming to improve the supply of feedstock among Resource and Energy Intensive Industries (REII) by introducing bio-based feedstock and retrofitting core production processes moving towards a circular economy.

RETROFEED main objective is to enable the use of an increasingly variable, bio-based and circular feedstock in process industries through the retrofitting of core equipment and the implementation of an advanced monitoring and control system, and providing support to the plant operators by means of a DSS covering the production chain. This approach will be demonstrated in five REII (namely ceramic, cement, aluminum, steel, and agrochemical) with the potential to reach in average an increase of 22% in resource efficiency and 19% in energy efficiency, with a consequent reduction in costs and GHG emissions of 9.3 M€ and 135 ktonCO2 respectively.

In the last decades, digital tools have become the key for handling complexities and evaluate opportunities in multiple industrial sectors. Industry 4.0 is part of this trend and is opening the door to the next phase of industrial digitalization where data, advanced analytical capabilities and new modelling techniques are leveraged to increase productivity with a specific focus on sustainability.

This report gives an overview of the current state-of-the-art of the industrial digital landscape having the opportunity to examine 6 different global players in the industrial sector. The information gathered are integrated with the input received from European research centers and technology companies, consortium members and subject matter experts for specific industries.

The project objective is to show that every industrial process, even highly efficient ones, have margins for improvement if new technologies, methodologies and tools are implemented. Examples are:

- Technological investment on core process retrofitting solutions
- Digital Tools
- New type of feedstock as raw material (e.g. plastic, waste)
- Cleaner or renewable fuels (e.g. sustainable biomass, waste)

3 ABBREVIATIONS

Acronym	Extended Name
AI	Artificial Intelligence
BI	Business Intelligence
BIM	Building Information Modelling
CNC	Computer Numerical Control
CRM	Customer Relationship Management
DB	Database
DCS	Distributed Control System
DNC	Direct Numerical Control
DT	Digital Twin
DRL	Digital Readiness Level
DSS	Decision Support system
EAF	Electric Arc Furnace
EPC	Engineering, Procurement and Construction
ERP	Enterprise Resource Planning
ETL	Extract, Transfer and Load
FDA	Fast Data Analyzer
HMI	Human Machine Interface
ICT	Information and Communication Technologies
IIoT	Industrial Internet of Things
IoT	Internet of Things
IT	Information Technology
KPI	Key Process Indicator
MES	Manufacturing Execution System
ML	Machine Learning
MOM	Manufacturing Operation Management
M&C	Monitoring and Control
NC	Numerical Control
OEM	Original Equipment Manufacturer
OT	Operational Technology
PLC	Programmable Logic Controller
PWC	PriceWaterhouseCoopers
REII	Resource and Energy Intensive Industries
RTD	Research, Technology and Development

R&D	Research and Development
SCADA	Supervisory Control and Data Acquisition
UA	Unified Architecture
VPN	Virtual Private Network

4 SCOPE OF THE REPORT

This report objective is to give a high-level overview of the current status of digitalization in the manufacturing sector followed by a focus on the 5 different REII represented by 6 project partners.

The instrument and tools represented in this report includes monitoring and control systems, planning and operative tools, decision making software, enterprise systems and simulations tools. These tools are described in detail in the context of the industrial IT architecture of each industrial partner, which adapted during the years following the main phases of industrial automation and control.

Chapter 5 gives a general overview of the current status while chapter 6 describes more in detail each industry situation with the description of specific tools and application widely adopted in the market.

5 INDUSTRIAL DIGITALIZATION

In the following paragraphs a high-level overview is given providing the reader with enough knowledge to understand the main aspects of modern industrial system architectures and how RETROFEED solutions could be integrated within the operation of a manufacturing plan.

5.1 Overview of Industrial Digital Maturity

The last industrial revolution may have started in the digital service sector but in the past decade heavy industries are slowly embracing the new digital wave with the design and development of specific tools that could help their manufacturing processes increasing productivity and therefore competitiveness.

The whole manufacturing sector digital maturity is currently scattered with some sectors only now entering what is commonly called industry 4.0, while others are still lagging with minimal level of digital capabilities applied to their processes. Also, within the same industry or sector, there are quite significant differences with global players that have heavily invested in digitalization and small, niche, players falling behind but with enormous opportunities ahead.

We can identify 4 levels of digitalization starting from Industry 1.0 to the latest trend of industry 4.0. A high-level description of the 4 levels is:

- Industry 1.0: Sensors are connected to some equipment and data are used to monitor some processes and main equipment.

- Industry 2.0: this is the status of many of today's manufacturing companies. ERP system are installed and used to monitor the overall enterprise with some process also equipped with automation technologies to control the operations. Data are collected at field level for monitoring and control purposes with simple data analyzer to keep track of high-level trends.

- Industry 3.0: the most advanced manufacturing players in different industries are currently at this stage of digitalization. Advanced process control and automation is in place with robotics and equipment connected to improve control and productivity. Data also play a big role with manufacturing execution system (MES) used to automate and optimize tasks. Industry 3.0 saw a big leap forward in the refining and chemical industry where safety and shut downs protocol became necessary to insurance the resiliency and the security of the operations.

- Industry 4.0: the next step in digital maturity will see the use of advanced optimization and analytical tools (e.g. Machine Learning, artificial intelligence, advance modelling) to optimize operations, adding value to both the assets and the quality of the final products. Real-time or quasi real-time data are widely used across different departments in the organizations and cloud infrastructure is leveraged to improve the analytical power and capabilities of the enterprise.

Taken from PWC report [1] about the shape of digital manufacturing about digitalization performed in 2020 the main reasons enterprises are increasingly investing in digital solutions are:

- Increase Production Efficiency
- Better control of digital factories
- Increase flexibility towards production and customers wishes
- Better ability to react to volume fluctuations
- Sustainability improvements
- Better product customization
- Reduction in logistics and supply chain costs

These improvements require a combination of factors to be successfully achieved. From technology to operations, from business to people management, all aspects of a company's know-how need to adapt to the new paradigm of a digital factory in order to compete in each particular market. RETROFEED focus will be on the technological and operational side of the business increasing the competitiveness of the consortium partner's companies through increased sustainability in the operations and therefore increased productivity thanks to a direct reduction in operative production costs.

In order to make this step forward, the project will integrate innovative solutions to increase operations flexibilities, modern sensors capable of collecting additional data, improved monitor and control system at factory floor level and ultimately an advanced Decision Support System capable of integrating a Digital Twin of the factory's core processes and optimize the surrounding operations for efficiency improvements.

In the following paragraphs a further explanation of current enterprises IT and data architecture is given with a focus on how RETROFEED will help in improving the current status of the system.

5.2 Industrial Digital Architecture

Future developments in the industrial IT architecture are based on the integration between IT and OT. As a reminder, IT or Information Technology, in an industrial context, is the use of computers to store, retrieve, transmit and manipulate data in business activities, and it's considered a subset of the wider ICT space. Instead, OT or Operation Technology, which could be considered as another form of IT at factory floor level developed to directly monitor and act over processes inside a factory. Examples of OT system are SCADA, PLCs system, Computer Numerical Control (CNC) or Direct Numerical Control (DNC) systems.

The IT/OT integration proved to be the key in the development of modern MES systems where real-time monitoring of the processes and overview over production costs, maintenance schedule and quality control helped in increasing the productivity of the plants. Recent advancements in IT technology, with increase hardware and software capabilities, created new challenges finding the limits of the current MES systems and opportunities to leverage digital platforms deeper inside the industrial factory. New sensors and technologies (e.g. Wireless sensors, IIOT Devices) will give a boost to productivity reaching many of the objectives expected by future digitalization efforts. Unfortunately, inadequate IT infrastructure, capital required and hesitation inside companies in adopting new technologies are sometimes a drag to the wide adoption of the latest state-of-the-art technologies.

A typical architecture based on ISA-95 standard is shown in Figure 1 as an example of system integration:

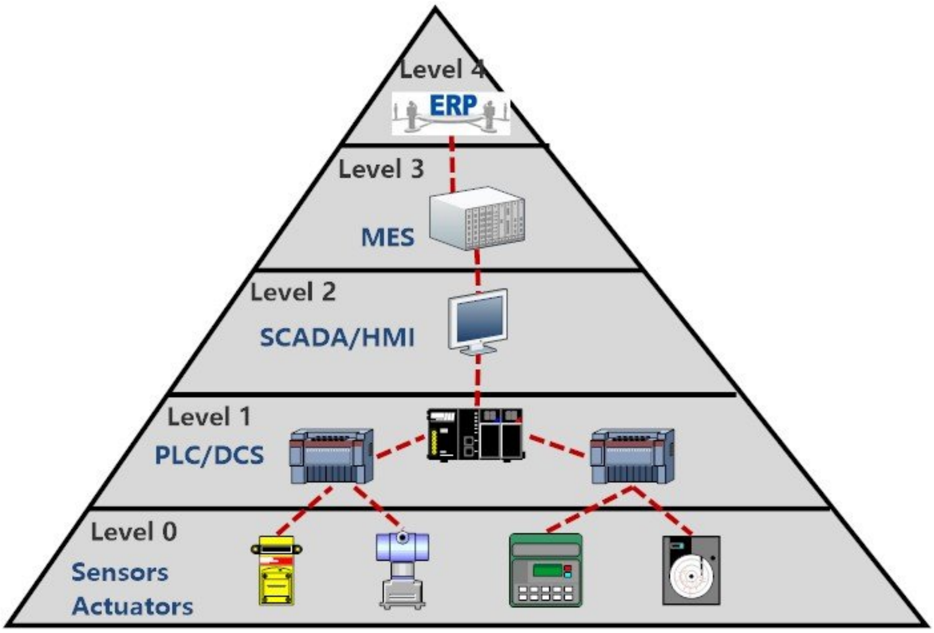

Figure 1: ISA-95 standard Architecture

An initial overview of RETROFEED partners digital architecture was obtained after a series of questionnaires, asking direct questions to consortium partners. Such questionnaires were used in order to understand the current status and how the digital solutions envisioned in the project, mainly the digital twin and the Decision Support System, could be integrate and at what level should be used within industrial processes.

In Figure 2 a high-level architecture is given based on the response provided by the different partners involved in the various tasks of the project and responsible for the different industries.

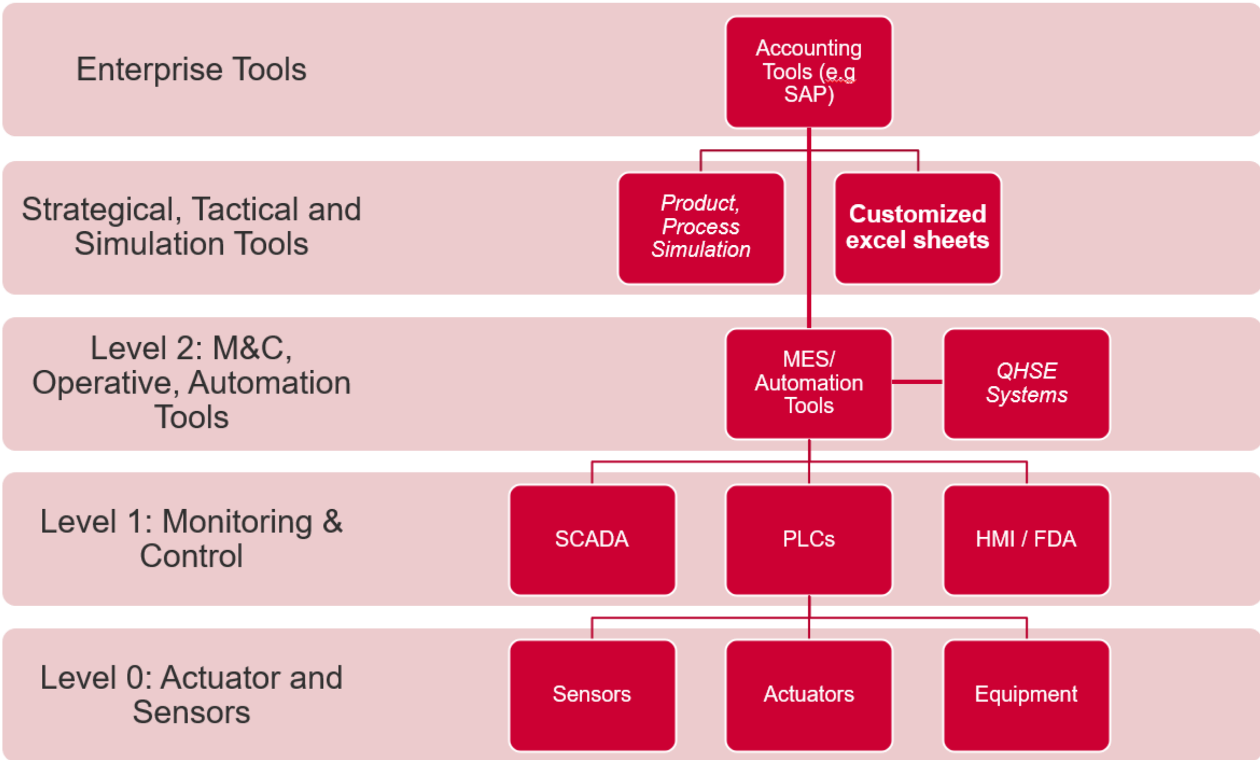

Figure 2: Common Architecture of RETROFEED industrial partners

The diagram is divided in different levels following the typical pyramid scheme where on the bottom there is the factory floor with sensors, actuator and equipment which are connected to a level 1 system collecting data through PLCs connected to a SCADA system. Depending on the industry a first level of analysis is done to keep track of the processes through the Human Machine Interface (HMI) platform or a dedicated Fast Data Analyzer (FDA).

Data collected at this level and used for monitoring and control (M&C) are then forwarded to a higher-level Manufacturing Execution Systems (MES) where technicians are able to monitor automated processes KPIs, evaluate alarms, analyze trends and take decision for the process phases. Not all the partners have an integrated and dedicated MES system, while among the partners that are equipped with such systems, the level of sophistications vary substantially making it difficult to quantify the importance and the usage of the tool within each operation. In some advance case, the MES is coupled with auxiliary tools capable of evaluating different aspects of the manufacturing process such as quality, environmental issues and safety of the overall operations. Business Intelligence system are also deployed, in very few cases, for a quick feedback of the main process KPIs.

At strategic level, where retrofitting, investments, short-term and long-term operational planning decisions are taken, is where the lack of dedicated tools and software was a common aspect among all the partners analyzed. Decisions are usually taken base on the experience of the engineers, unit leaders or operators with the support of custom and internally developed spreadsheets, in which the know-how of the company's operations is used to evaluate data and the best approach to the production process. Some partners only have spreadsheets dedicated to a specific process, instead of the entire value chain, and they only monitor that the process phases are within an acceptable range of parameters regardless of the final output. Quality control is then the key to adjust the main parameters in case specifications are not compliant with the production plans.

Retrofitting and capital expenditure decisions are always taken using spreadsheets were the necessary data are collected from the different system and integrated within a project financial plan. What-if analysis, simulations or optimization are not part of the current process which results in a very static approach towards the overall decision-making process.

Simulation and design tools (e.g. Autodesk Inventor, Dassault System products, Ansys) are used within technical department for product or process development but are not considered as support for the operational decision-making process yet. Some partners also outsource the simulation aspects of the facility or the equipment either to owner engineering companies (EPCs) or directly to the manufacturer of the specific equipment. At last, all the partners have deployed an Enterprise Resource Planning (ERP) system to control procurement, logistics and resource aspects of the manufacturing plant.

5.3 Data Management

Another important aspect of modern IT/OT architecture is how data are stored, retrieved, used and flow within the plant and the different process units. Depending on the level of complexities of the plants, the number of different production phases, the length of the process and the interdependencies among the process phases, data can be stored in a single or multiple databases with the historical data stored for months or years depending on their importance.

Data are usually collected from the field through sensors or other equipment system and communicated to the PLCs using a fieldbus network (e.g. Profibus, Profinet, foundation fieldbus, etc.) (Figure 3). SCADA systems connected to the PLCs are then used to visualize, monitor and control operations giving the possibilities to operate on the process sending signal back to the PLCs. Data displayed in the Scada system can be sent to data historian (e.g. GE proficy, Siemens Wonderware) to allow statistical analysis and trending overview. An important aspect to be considered is the protocol used to transmit the data among different machines. The most used standard is OPC UA (unified Architecture), direct evolution of the firsts OPC protocol for data access, alarms and events and historical data access. This standard allows different machines, often designed and bult by different OEMs, to communicate with each other or to normalize the data for higher level legacy systems for data management, monitoring and control.

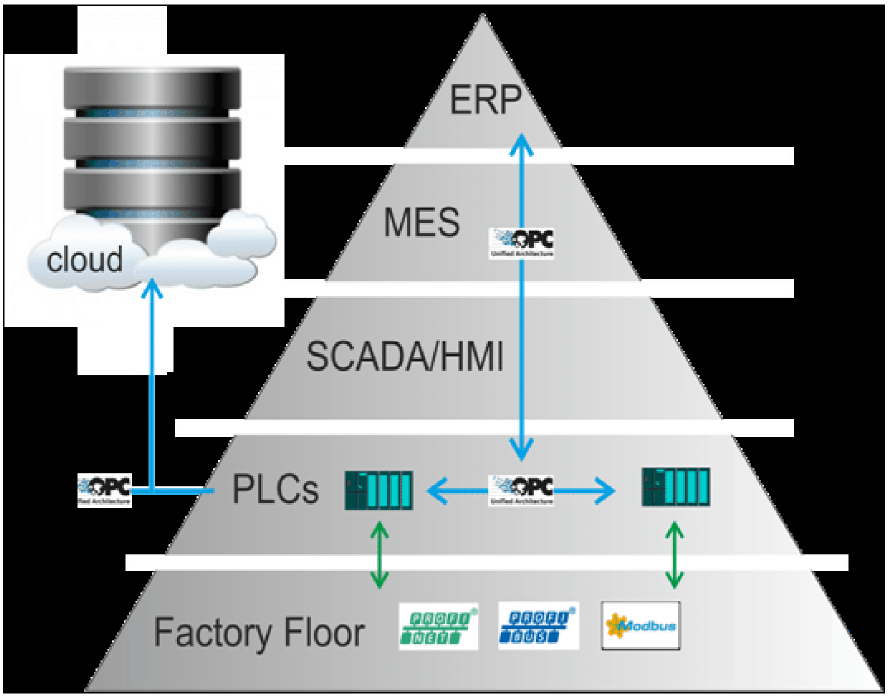

Figure 3: Example of Fieldbus and OPC standard integration within industrial automation architecture

RETROFEED's partners have similar architectures with some equipped with more advanced databases management systems where data are stored for long period of time in order to increase the depth of the analysis paving the way to the digital factory of the future. Data saved in the databases (e.g. SQL, MySQL etc.) are often exported into the abovementioned spreadsheet in order to take operative, strategic and tactical decisions on timely base.

RETROFEED's DSS, currently under development, will be designed to add advanced capabilities to the decision-making process, partially or completely substituting the spreadsheets used within the company's operations. It will integrate advanced ML models capable of finding correlations among data to enhance production and find new opportunities for process development and a digital twin (DT) that will be used to simulate the core process giving to the user the opportunity to see directly how certain decision could affect the overall process (what-if and scenario based analysis). The models will be integrated with the development of additional process models, designed to include in the future system all the processes that could affect the decision-making process in that particular area of the factory or for that particular process.

After this overview of the digital status of the different industries, in the next chapter the different industries, focus of RETROFEED, will be analyzed with a list of tools currently deployed and used daily in real manufacturing operations.

6 TOOLS SEGMENTATION BY USE

In this chapter, a description of the common tools used in each industry object of RETROFEED is delineated, integrating the information collected by the industrial partners, the RTDs and the technical partners involved in the project.

The project focuses on 5 very different industrial sectors: Ceramic, Cement, Aluminum, Steel and Agro-Chemical. This wide and heterogeneous group of sectors makes a direct benchmark of the different digital readiness level (DRL) difficult but, on the other hand, interesting to understand the potential for improvements in the different sectors.

For each industry, the description of the tools follows the pyramidal scheme described in the previous chapter starting from the data management and control architecture system, monitoring and control and finishing with an overview of the ERP systems used by the industrial partners.

6.1 Aluminum

The data management and control system used by ASAS (Table 1) is similar to the automation standard described before. Equipment is connected through Device-net fieldbus and the SCADA system is made by Rockwell Automation which communicates using the OPC protocol and visualize data through the embedded interfaces. Data are stored in a single SQL database which could be accessed by external users via a dedicate VPN.

Table 1: ASAS System Architecture

CONTROL ARCHITECTURE INFORMATION	
Current control architecture	PLC CPU with DeviceNet
Fieldbus used	DeviceNet
Visualization tools	HMI – SCADA
Data communication protocol	OPC
Management software currently used	Rockwell Factory Talkview Runtime addition V6.0
Database of historical data	Single central SQL database
Data or connection availability from external sources	Yes via VPN
Data need to be stored on site (e.g. local server) or it is allowed to store them on cloud?	Only local
Is there any historical data of the process control stored and accessible? For how long is data usually stored?	Storage depends on type of data

Monitoring and control of the process is also done through the SCADA and HMI system (Allen Bradley RS View) connected to the PLCs. It is used to monitor the main process parameters helping the decision about operational actions to be taken. The system main use, in the context of the project, is for the melting furnaces giving the possibility to visualize data (temperatures, flows, pressures, etc.) without human intervention, collecting them remotely through the sensors installed on the equipment. Internally, it is also used to evaluate consumption and some of the combustion parameters.

At Level 2, and as enterprise wide system, the factory uses SAP – MES where data are stored for a longer period and used to run operations beyond the single process. In this case, it is used to handle the inventory and the selection of the right raw material for each batch. It also shows the major operational KPIs giving the operator an immediate way of controlling if operations are following the expected plan.

Currently there are not operational, strategical, and tactical tools specifically developed for those purposes. Decision, what-if analysis, and optimization scenarios are usually executed using customized spreadsheets with data collected either from the SCADA system or the MES historian. MS Excel is also the selected tools for evaluate budget and medium to long term operational plans.

Simulations tools such as ANSYS and QForm are used to simulate some operations (e.g. QForm for die design) or to make mechanical and thermal simulations of products profiles and specifications.

In Table 2 a list of tools is given with the main notes regarding them:

Table 2: ASAS Tools table

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
Rockwell Factory Talkview Runtime addition V6.0	M&C	1	Real time HMI systems for real time monitoring and control of each machine	Charts, tables, KPI	Excel files
SAP MES	M&C	2	Factory wide monitoring and control system for controlling process input and output	Charts, tables, KPI	Excel, Historian and SQL DBs
MS Excel	Strategic, Tactical, Sim	NA	Used to evaluate budgets, investment decisions and high-level analysis	Charts, tables, KPI	Excel Files
SAP Enterprise Management	Enterprise Tool	Enterprise	Monitor consumptions, stock and accounting data		Excel files
QForm ANSYS	Simulation	NA	Used to simulate product and dies design		

Additional system used in the factory measure data of auxiliary’s system such as emission control (online) and energy consumption at factory and process level.

Most of the tools used in the industry are based on the fieldbus, PLCs, SCADA/HMI initial selection. The decision regarding monitoring and control tools also is tight to the equipment manufacturers which can influence highly the selection of the system architecture and infrastructure. A List of few other tools used by some of the biggest player in the industry is given in Table 3.

Table 3: Tools used in the aluminum industry

DIGITAL TOOLS NAME	DESCRIPTION
Impact CES	Impact CES is an Enterprise Platform application that gives finance and operations leaders access to the results that enable you to make better business decisions.
PI by Osisoft	PI System a is process intelligence platform able to collect, analyze, visualize and share large amounts of high-fidelity, time-series data from multiple sources to people and systems across all operations.
Autodesk Suite	One of the most used engineering tools for design and simulations of finishing goods, processes and infrastructure projects.

6.2 Steel

The analysis of the tools used saw the contributions of two different partners giving the possibilities of understanding the possible architecture's combination and the integration with SCADA/HMI system and advanced MES tools (Table 4). The steel industry, within the metal processing sector, is one of the most advanced industry among the one focus of RETROFEED. MES, absent in other industries, were deployed years ago and are now fully integrated in plant operations and decision-making process with the company's know-how almost fully embedded in the tool with additional support system for advanced analysis.

Table 4: Ferriere Nord and Silcotub Data Management Architecture

CONTROL ARCHITECTURE INFORMATION	FERRIERE NORD	SILCOTUB
Current control architecture	PLC CPU with ProfiBUS DP Network	PLC CPU with ProfiBUS DP Network
Communication schemes	Cyclic polling	-
Fieldbus used	Profibus	Profibus
Visualization tools	PLC S7-400	PLC 400 SIEMENS
Data communication protocol	SCADA: Copadata ZenOn	HMI
Management software currently used	LIV2	-
Database of historical data	LIV2	Several DBs
Data or connection availability from external sources	No	Yes via VPN
Data need to be stored on site (e.g. local server) or it is allowed to store them on cloud?	Local Sever offline from the Internet (both Level 1 and Level 2)	Depends on the servers

Is there any historical data of the process control stored and accessible? For how long is data usually stored?	Level 1 for some days. Level 2, some data stored for years or for days.	Level 2 usually for 6 weeks

Ferriere Nord, the first of the two steel maker project's partners, level 1 monitoring and control system is provided by Danieli, a manufacturer of equipment and services for the metal sector, with HMI and FDA (Fast Data Analyzer) integrated for the widest process view possible. Level 2 instead is provided by SMS – Concast, a leader in digital tools for the metal industry. It usually collects all the relevant data from the level 1 system and provides a higher-level overview of the all plant's processes from the scrapyard to the continuous casting machine. In the context of RETROFEED, the system manages the automation around the EAF functioning, with 90% of the operations covered automatically and minimum human intervention required. Each system manages hundreds of variables such as temperatures, flows, valves' state, actuator positions, pressures, etc. Level 2 system has some business intelligence capabilities to monitor trends and perform small analysis with the available data. Strategic, tactical and operational decision beyond process control, is currently done using custom developed spreadsheets, similar to the aluminium case, that in the hands of the operators support operational decisions on medium to long term basis (Table 5).

The overall system lacks an advanced optimization and analytics platform capable of improving further the operations leveraging upon the enormous amount of data generated in each part of the process. The digital tools envisioned in RETROFEED aim at filling this void at least for what concern the EAF and feedstock selection process.

Table 5: Ferriere Nord Digital system

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
Danieli HMI + FDA	M&C	1	Receives and visualize sensors data	Values	To Level 2 system
SMS Concast	M&C + Automation + process mgmt	2	Real time monitoring and analysis. Data Storage	Charts, tables, KPI	Excel, Historian DB
Excel	Strategic, Tactical, Sim	NA	Used to make Operational decisions about the process	Charts, tables, KPIs	

On the other hand, Silcotub currently is using 7 different tools for plant monitoring, control, process automation and business intelligence with respect to the different department within the factory (e.g. factory floor, quality control room etc.).

Field data, as explained previously, are collected through a series of PLCs with an HMI system for operators' control of sensors' data like temperature, consumption and process status. Data are not collected at this level and are sent to the level 2 system for storage into several DBs. Level 2 is used by both operators and plant management for process monitoring. Data are shown in real-time or used to develop statistics and charts of the current operations with the possibility to export them in commonly used format like excel files type or csv, data are then stored for approx. 6 weeks.

At a higher level, Tenaris has developed a factory control system (AutodonWeb) for controlling the following operations:

- Interruption Management
- Production Reports
- Production Schedule
- Scrap yard management
- Steel Catalogue
- Steel-shop tracking
- Energy monitoring and forecast based on production plan

The tool takes the data from level 2 databases and store those data for a longer period giving the possibility to execute more detailed analysis with the monitoring of specific KPIs, the creation of alarms, summary table and charts. Export in other file formats is possible.

Connected to these two main tools for monitoring and control there are a series of other application used in specific department for different activities. For instance, Tenaris uses two tools for safety and non-conformity measurement internally called TSE (Tenaris Safety Environment) and QHSE BI, a business intelligence platform built to monitor quality, health, safety and environmental data.

Another set of applications are used for material quality check and they are integrated with the main factory control system. They are all designed to perform analysis, create charts and tables and trigger alarms in case of non-conformity within the operations or the final product (Mostly related to steel pipe quality).

At a more strategic level, SILCOTUB uses a mix of spreadsheets plus some of the capabilities embedded within the factory control system for data management. Decision about retrofitting opportunity, what-if analysis and investment are mainly taken using MS Excel as main application.

The overall Tenaris enterprise use SAP for accounting activities, warehouse management and everything connected to non-core business operations.

In Table 6 the tool list is briefly summarized for an easy access:

Table 6: SILCOTUB Digital Tools

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
PLC app + HMI	M&C	1	Receives and visualize sensors data	Values	To Level 2 system
Level 2 app	M&C	2	Real time monitoring and analysis. Data Storage	Charts, tables, KPI	Excel, Historian DB
AutoDonWeb	M&C	2	Use to automate activities and factory control	KPI, Charts	Excel, PDF
TSE (Tenaris Safety Environment)	M&C	2	Tracking of HSE parameters and risk analysis	KPI	Excel
QHSE Power BI	M&C	2	Business Intelligence platform to visualize HSE data	KPI, Charts	
IAM (Quality control)	M&C	2	Monitor the non-conformity to the action plan	KPI	Excel
Quality Control	M&C	2	Control product quality, rejections and perform analysis	charts	Excel
PLC app + HMI	M&C	1	Receives and visualize sensors data	Values	To Level 2 system
Level 2 app	M&C	2	Real time monitoring and analysis. Data Storage	Charts, tables, KPI	Excel, Historian DB

During the information collection period, it was also asked to the technological partners to provide details about known tools used in the steel industry. In the following table is described a tool used in the industry by some of the partners involved in the process.

In this case the tool is used to monitor and control the main operation of an Electric Arc Furnace (EAF) (Table 7).

Table 7: EAF Tool Description

MONITORING TOOL	
Tool name	EAF Tool
Tool description and use	EAF / LF Process Monitoring, Decision Support in optimizing EAF energy consumption (Oxygen, Carbon)
Advantages of this tool	Graphic Interface for monitoring of all the significant process KPIs and parameters / Alarms and operating suggestions
What is missing in this tool that would be useful for you?	N.D.
Relevant parameters/variables monitored	EAF process parameters (electrical consumptions, Natural gas / Oxygen consumptions, cooling parameters, off gas parameters)
Data visualization (charts, KPIs)	Process data charts and calculated Performance indicators (quality and efficiency KPIs)
Useful export files generated by this tool	Database tables with calculated KPIs and variables

Other tools have been developed internally, such as TATA Steel Versiondog for multi-factory system management or PSI Metals widely used by global players (e.g. Arcelormittal, Voestalpine).

PSI Metals should be especially mentioned has one of the tools capable of integrating all the capabilities of a level 1, level 2 and level 3 approach combining an MES with the ERP system for planning, scheduling, logistics and production monitoring, control and optimization (Table 8).

Table 8: PSI Metal suite

MONITORING TOOL	
Tool name	PSI Metals suite
Tool description and use	PSI Metals suite supports the monitoring, control and optimization of the entire metal manufacturing supply chain
Advantages of this tool	Consolidation of different tools in one single system
What is missing in this tool that would be useful for you?	NA
Relevant parameters/variables monitored	Schedule, process OEE, costs, energy consumption, product quality etc.
Data visualization (charts, KPIs)	Process data charts and calculated Performance indicators
Useful export files generated by this tool	Excel spreadsheet, DB

6.3 Ceramics

The ceramic industry is currently facing a radical digital transformation now entering the phase in which other industries have entered years ago with the introduction of advanced MES and ERP systems.

RETROFEED's partner Torrecid is currently using a data architecture like others industrial players with the PLCs connected to a SCADA system and a MOM (Manufacturing Operation Management) (Table 9).

Table 9: Torrecid Control Architecture

CONTROL ARCHITECTURE INFORMATION	
Current control architecture	PLC CPU with Profinet
Fieldbus used	Profinet
Visualization tools	HMI – SCADA WINCC `PROFESIONAL – Visual Basic 6.0
Data communication protocol	OPC
Management software currently used	ERP – MES/MOM
Database of historical data	Single SQL Database
Data or connection availability from external sources	VPN
Data need to be stored on site (e.g. local server) or it is allowed to store them on cloud?	Local server
Is there any historical data of the process control stored and accessible? For how long is data usually stored?	Historian Available

Monitoring and Control System at level 1 is managed through the SCADA Wincc system developed by Siemens. It used to manage all the parameters of the furnace such as pressure, temperature inside furnace, temperature of exhaust gases; gas and O_2 flow. RETROFEED solutions will add control and measurement over raw materials input, frit output, cooling water flow and temperature (to be regulated with frit amount), O_2 inside furnace, combustion air temperature and combustion air flow. At level 2 an ERP system is used to manage factory level parameters such as inventory management and client orders. At strategic, operation and tactical level the company is currently using MS excel as main tool for decision-making with data retrieve directly from the data historian connected to the SCADA system. Below the table with the list of tools used inside Torrecid (Table 10).

Table 10: Torrecid Tools List

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
SCADA connected Visual Basic 6.0	M&C	1	Receives and visualize sensors data	Values	
ERP system	ERP	Enterprise level	Data Storage and enterprise management	Charts, tables, KPI	Excel, Historian DB
MS Excel	Strategic, Tactical, Sim	-	Used to make Operational decisions about the process	Charts, tables, KPIs	
SCADA connected Visual Basic 6.0	M&C	1	Receives and visualize sensors data	Values	
ERP system	ERP	Enterprise level	Data Storage and enterprise management	Charts, tables, KPI	Excel, Historian DB
MS Excel	Strategic, Tactical, Sim	-	Used to make Operational decisions about the process	Charts, tables, KPIs	

As Explained at the beginning of the paragraph, the ceramic industry is experiencing a digital transformation with tools that have been developed in recent year to automate processes increasing the capability to respond to modern and complex manufacturing systems. MOM have seen a big development in the industry with OEMs that are now offering complete platform for the integration of new equipment in the factory supply chain.

All the major ceramic equipment suppliers are currently developing platform and tools that, combined with the existing SCADA, could make better use of data collected by traditional and innovative IoT sensors. For instance, System Ceramics offers Prime, a complete MOM tool for operational management capable of connecting different departments and retrieve data from different system for improving plant performances. Like SACMI's H.E.R.E. platform for connecting single machines and processes to multiple equipment, warehouses and connected processes.

In the following a list of tools (Table 11) currently under development is given to depict a wider picture of the digital transformation in the ceramic industry.

Table 11: Digital tools used in the Ceramic Industry

DIGITAL TOOLS NAME	DESCRIPTION
Prime (System Ceramics)	Manufacturing Operation Management System with 3D capabilities for managing an entire ceramic plant from the warehouse to packing and shipping units.
H.E.R.E. (SACMI)	It is a new generation plant supervisor capable of governing the entire process, from a single machine to several interconnected production units.
BMR Digital Line (BMR)	Remote finishing line management system
Vulkano project tool	Predictive tool for the evaluation of furnace status using the integration of Life Cycle Assessment (LCA), Life Cost Cycle (LCC) and thermo-economic analysis (TE). The tool can also be used and adapted for other SPIRE industrial sectors
Ceramic ERP (Munim)	ERP developed specifically for the ceramic industry

6.4 Cement

The cement has seen substantial investment in recent past for what concern digitalization aspects. Companies like FLSmith and Siemens have developed advanced tools for managing the process trying to increase the overall operational efficiency in a very competitive industry. The major industry players are currently looking to digitalize most of the supply chain aspects (DSC), from quarrying management to logistics, production, packing and customer relationship with in some cases direct integration with infrastructure project and BIM systems.

Secil as part of its digitalization strategy has deployed multiple systems to manage different aspects of the plant and through RETROFEED a step forward towards advanced analytics (e.g. Digital Twin, ML, AI) and a complete decision support system platform will be made.

The control architecture is based on a PLC connected to MIPRO SCADA system developed by schneider electric and another Scada ECS system developed by FLSmith. In Table 12 is given an overview of the main control architecture:

Table 12: SECIL control Architecture

CONTROL ARCHITECTURE INFORMATION	
Current control architecture	PLC CPU
visualization tools	SCADA – MIPRO; SCADA - ECS
Data communication protocol	Web API, ODBC
Management software currently used	MIPRO + ECS
Database of historical data	Single DB
Data or connection availability from external sources	VPN
Data need to be stored on site (e.g. local server) or it is allowed to store them on cloud?	Preferably on site
Is there any historical data of the process control stored and accessible? For how long is data usually stored?	Historian Available. Data stored for approx. 18 months

The company currently employs 8 different tools for monitoring and control systems particularly around the kiln process area where temperatures, speed, pressure and other parameters need to be closely monitored to avoid instabilities in the process.

At enterprise level the company uses SAP managing all the aspects not strictly related to the core process. For operational, tactical and strategic decisions there are not customized tools in use but the company is using a combination of spreadsheets, data retrieved by the SCADA systems and experience of the operators to decide operational plans, strategic investment or any decision that does not concern the immediate monitoring and control of main parameters.

In Table 13 a description of the main tools used within SECIL operations is shown.

Table 13: SECIL current digital tools

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
ECS v8.3 (from FLSmidth)	M&C	1	Scada System for cement production	All process data from PLCs	Excel files
Monitor Pro (from Schneider)	M&C	1	Scada System for most of the plant departments (being replaced by ECS v8.3)	All process data from PLCs	Excel files
Polab (from ThyssenKrups)	M&C	1	Quality Control System	All plant quality data	Excel files
Kiln Thermography (from Durag)	M&C	1	Online temperature distributions directly from the kiln and clinker cooler	Online flame Temperature	Video, Excel files
Gammametrics (from Thermo Fisher)	M&C	1	Cross Belt Analyzer for real-time online elemental analysis	Chemical Analysis of raw materials	Excel, KPIs, Charts
Genisys (from Appsyscore)	M&C	1	Environmental Emissions Management System	main kiln's gas emissions	Excel files
Kiln Shell Scanner (from HGH Systems)	M&C	1	Continuous surveillance of kiln shell temperature	Kiln temperature	Print screen only
LIMS (from Labware)	M&C	1	Laboratory information management system	All Quality data	Excel files
SIMEQ (from SIMEQ ApS)	M&C	1	Process Optimization System	data for Process optimization	Excel files
MS Excel	Strategic, Tactical, Simulative	NA	Used to evaluate budgets, investment decisions and high-level analysis	Tables, KPIs, Charts	Excel files
OSISOFT PI	BI – Enterprise Mgmt	NA	Used to store, visualize and make analysis about data	Process flow-charts, diagram, tables, KPIs	Excel files, txt
SAP	Enterprise Mgmt	NA	Monitor consumptions, stock and accounting data		Excel file possible

The entire industry has embraced the digital transformation of the past decades and it's currently ready to make a step forward towards a fully developed and deployed 4.0 paradigm where a new mindset regarding operational use of digital solutions and new technologies such as machine learning and artificial intelligence could enhance processes even more.

Other industrial leaders such as Cemex and Lafarge Holcim are investing heavily in industry 4.0 technology with solutions under development that are similar to the ones envisioned within RETROFEED Scope. Other important tools worth mentioning are shown in Table 14.

Table 14: Tools widely used in the cement industry

DIGITAL TOOLS NAME	DESCRIPTION
CEMAT (Siemens)	The process control system CEMAT is based over SIMATIC PCS 7 technology a solution for optimization of production potential in cement production.
ABB Operations management tools	A series of tools developed by ABB for the cement industry includes: business intelligence, operations and optimization capabilities.
Ecostruxure by Schneider Electric	An IIoT platform developed by Schneider Electric and also available for the cement industry. It integrates planning, optimization, operational monitoring and energy management systems in a single system.
CEMAT (Siemens)	The process control system CEMAT is based over SIMATIC PCS 7 technology a solution for optimization of production potential in cement production.
ABB Operations management tools	A series of tools developed by ABB for the cement industry includes: business intelligence, operations and optimization capabilities.

6.5 Agrochemicals

Agrochemical, similarly, to the previously described industry, have seen an acceleration in digital transformation strategies across the industry. Currently the industry is quite concentrated, with global players consolidating their position through mega mergers and acquisition. To remain competitive, companies are fully embracing the digital transformation with the deployment of technologies capable of reducing the distance between farmers' needs and chemical production in order to retain customers and attract new ones willing to have a closer relationship with suppliers.

Fertiberia SA, a medium size company in the agro-chemical sector, whose objective within the RETROFEED project is to reduce the cost of production of its NPK fertilizer through a combination of different feedstock and digitalization opportunities. The following control system overview helps to understand how field data are retrieved, transferred and stored in Fertiberia's digital architecture.

Similar to the other industries, they use a PLCs system connected with different fieldbus like modbus, profibus or ethernet-based bus systems (Table 15). PLC are Honeywell C-200 connected to a SCADA system.

Table 15: Fertiberia's Control Architecture

CONTROL ARCHITECTURE INFORMATION	
Current control architecture	PLC-SCADA
Fieldbus used	Modbus, profibus, ethernet
visualization tools	SCADA
Data communication protocol	Internally developed protocols
Management software currently used	Honeywell Experion DCS
Database of historical data	Multiple DBs
Data or connection availability from external sources	NA
Data need to be stored on site (e.g. local server) or it is allowed to store them on cloud?	Preferably on site
Is there any historical data of the process control stored and accessible? For how long is data usually stored?	Historian Available

At level 1, monitoring and control systems, Fertiberia uses the distributed control system (DCS) developed by Honeywell. Instrumentation is online and connected to the DCS giving the operator the possibility of controlling some instrumental loops. Specifically, it monitors temperatures, pressures, pH level, raw material quantities and other important variable important for the process.

At monitoring level, it is also used a laboratory management tool for analysing raw material and finished goods. Slow and costly it needs to be improved in order to provide timely results and increase plant productivity based on those.

At operational, strategical and tactical level the company uses a series of internally developed spreadsheets to take decision regarding production plans, raw material selection and investment decision for retrofitting and upgrading actions in the NPK process. The two main tools are divided in:

- NPK material balance and optimization tool. It is used for selecting the optimal combination of raw material based on the expected product output.
- NPK energy and water balance tool. Complex tool used to simulate energy and water balances in a reaction. It is used when new reactions are evaluated to calculate results and balancing of the reaction.

Other internally developed spreadsheets are also used at corporate level for investment decision regarding, for instance, plant expansion or experiment for understanding new production approaches such as the one proposed within RETROFEED.

Table 16: Fertiberia Digital Tools

TOOL NAME	TYPE	LEVEL	DESCRIPTION	OUTPUT	EXPORT
Honeywell DCS - Experion	M&C	1	Receives and visualize PLCs data	Process Data	reports
Laboratory tests management	M&C	1	Raw materials tests for composition and specifications and final product test for composition and physical properties	Composition, contaminants, humidity, hardness, friability, caking grade, etc.	Report
Internal tool for material balance optimization in the NPK process	Operational	-	Used to make operational decision about raw material mixing	Raw materials, nutrients, additives, product, compositions, etc.	Excel files
Internal tool for energy and water balance in the NPK process	Operational		Used to calculate energy and water requirements of reactions	Information from raw materials (including exact composition), water, temperatures, etc.	Excel files
Internal tool for Investment Decision Making	Strategical		Used to calculate financial input and output and take investment decision	Cost of raw material, energies, auxiliar material, fixes costs, investment cost, etc.	Excel files

In the context of RETROFEED, Fertiberia could embrace the digital transformation integrating its internally developed tools into a modern platform capable of handling data, optimize processes and run simulation and analysis. The combination of DT, plant wide value chain and machine learning models, planned within RETROFEED portfolio of envisioned digital tools, should help Fertiberia improving its current process finding correlations, synergies and optimization opportunities in a very complex manufacturing process.

At industry level, large players in the industry such as Bayer-Monsanto, Syngenta, BASF are all investing in digital technologies to improve the entire supply chain. Other tools worth mentioning in this analysis, and use by Fertiberia itself in other processes, are shown in Table 17.

Table 17: Additional Tools used in the chemical industry

DIGITAL TOOLS NAME	DESCRIPTION
ProSim	Simulation process tool for chemical plants.
Simatic PCS 7 (siemens)	Monitor and Control system tailored for chemical production plants with safety loops integration and simulation capabilities
Matlab	One of the most used software in engineering is also used in the chemical industry for mass and energy transfer calculations, equipment modelling, reactor design and control loops
Chemstation ChemCAD	CHEMCAD is Chemstations' software suite for process simulation. Features include process development, equipment design, equipment sizing, thermophysical property calculations, dynamic simulations, process intensification studies, energy efficiency/optimization, data reconciliation, process economics, troubleshooting/process improvement
ASPEN HSYS	Aspen HYSYS (or simply HYSYS) is a chemical process simulator used to mathematically model chemical processes, from unit operations to full chemical plants.
ASPEN Plus	Aspen Plus is a process modeling tool for conceptual design, optimization, and performance monitoring for the chemical, polymer, specialty chemical, metals and minerals, and coal power industries.

7 BENCHMARK AND INNOVATION POTENTIAL

What is clear from the previous chapters is the fact that digitalization in the industrial space is very difficult to benchmark considering the manufacturing sector as a whole. Metal and chemical industries started the digitalization process decades ago for safety reason and to fulfil the market needs for complex products which require complicated processes, sometimes difficult to put in place and monitor. Cement and ceramic followed the initial push for the installation of monitoring and control but have not seen the widest deployment of advanced MES or simulation systems like the metal sector for instance.

A heat map of the current digital situation of the different sector and partner was developed taking into account the information provided in the previous chapters. Metals manufacturer, ASAS, Ferriere Nord and Silcotub together with Fertiberia in the agrochemical sector all have very advanced monitoring and control system with some having developed BI, automation and optimization capabilities. For these industries the amount of data already collected is already substantial, opening the door to the development of more advanced tools such as the one under consideration within the project. Secil and Torrecid also have monitoring tools with multiple aspects of the operations monitored closely with some automation system already in place. Data and the necessity to install novel sensors in their process, in order to fully develop an advanced analytics platform, are the reason why they are still considered one step behind in the digital heat map (Table 18).

Sector	Sensors	Monitor & Control	Automation	BI – Advanced Analytics	Optimization
Cement	◑	◑	◔	○	○
Ceramic	◔	◑	◔	○	○
Steel	◕	◕	◕	◔	◔
Aluminum	◕	◑	◑	○	○
AgroChemical	◕	◕	◑	◔	◔

Maturity level: ● Advanced ◕ High ; ◑ Medium; ◔ Low; ○ Absent

Table 18: Heat Map of partner digital situation

Future industrial controls will likely move from the traditional schema of PLC/Line PLC/SCADA/MES-MOM to a software platform were data collected from the field, based on different type of sensors, are processed through some PLC or Numerical Control (NC) systems, with OPC UA as main communication protocol for sending data to the platform. The SW platform, through a gateway and the installation of some ETL (Extract, transform and load) module to clean and normalize data, will integrate specifically designed applications for different tasks shadowing the functioning of the current MES, ERP, CRM and SCADA system but taking advantage of all the aspects that new technologies already provides in other industries (e.g. banking, logistics, transportation, etc.). All factory data will be managed within the platform, giving faster access to the different departments, finding synergies and correlation among them in a very short time frame instead of the long lead time required by the silo approach of current systems.

In Figure 4 a high-level view of a future industrial platform is given, showing how the DSS can be included in the current industrial architecture without having to develop a completely new platform. This approach can be considered a first step towards a full integrated platform where even the ERP, MES and other tools like CRM and operative tools could be integrated in the SW infrastructure either on cloud or on premise as described before.

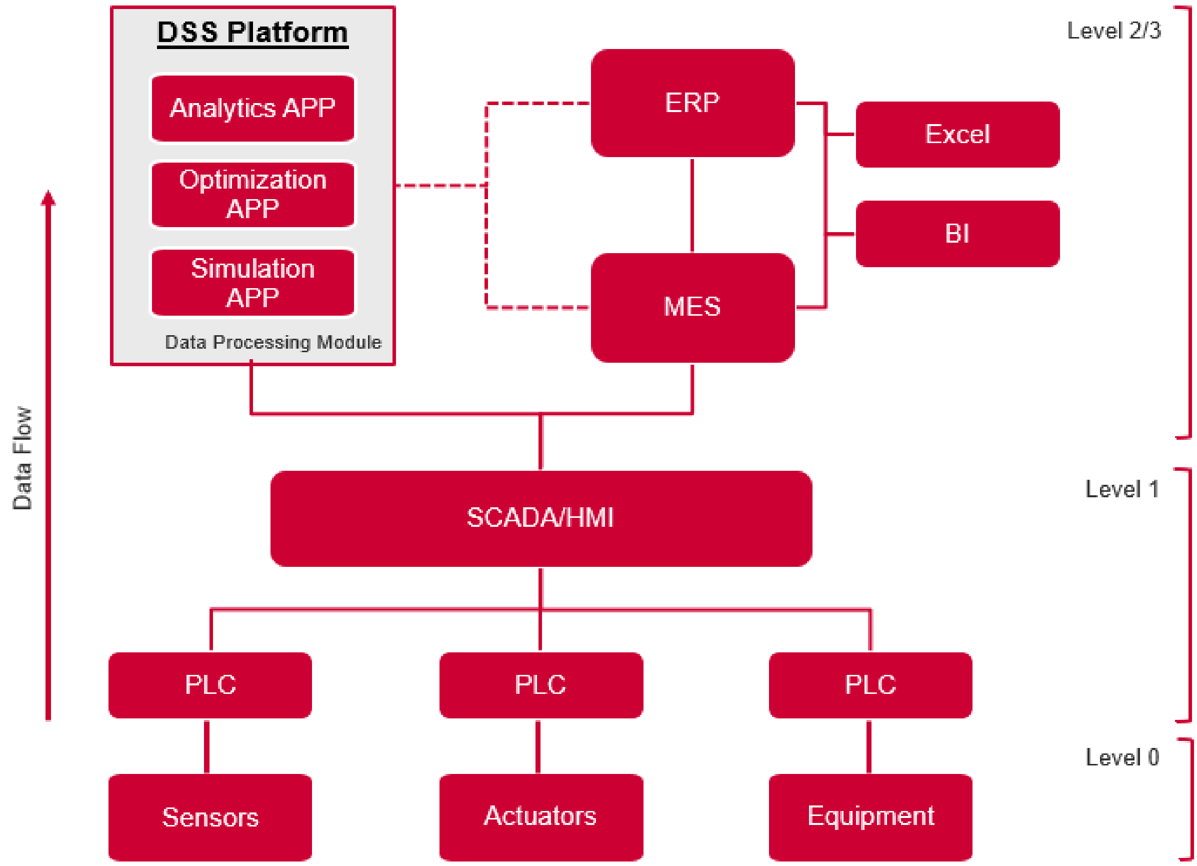

Figure 4: Integrated Industrial Platform

The DSS, coupled with the DT simulation capabilities, should be able to support the decision-making process initially integrating the custom-made spreadsheet and, in the future, substituting them once the advantage of having a dedicated application are clear together with the methodology of using it is leveraged within the company's operations.

Overall, the industrial partners could benefit greatly from advanced digital tools capable of handling not only the operations but also planning those in advance with a more dynamic approach capable of adapting to continuously changing conditions within and outside plant's operations. The envisioned DSS is clear that can be considered an important next step in industry 4.0 implementation.

8 CONCLUSIONS

RETROFEED project main objective, as explained in the first chapter of this document, aims at reducing the impact of energy intensive industries on the environment by replacing raw material and fuel with different feedstock through the retrofitting of core processes and connected equipment. To carry these activities and to monitor the increase complexity of the production processes digital tools will be developed to simulate, take future decisions, and improve production by leveraging additional data coming from novel sensors installed during the project.

As described in the previous chapters, integrating new systems in an already very complex process requires the development of a tool flexible enough to be used with the widest possible set of architectures, database, communication protocols and that is consider a step forward with respect to the current tools' portfolio adopted by each industrial case.

Though lacking the advancements seen in other industries, the manufacturing and industrial space is currently closing the gap, with industry 4.0 not only a forward-looking perspective depicted in laboratories and R&D center, but a reality that will become the norm in the near future. Embracing the new wave of technology, particularly on the software side, is foreseen to bring enormous advantages to the industrial sectors from supply chain improvement to production optimization, from optimal maintenance schedule to cost and revenue enhanced control, from managing energy in a sustainable way to increase productivity and product quality.

In addition, European companies, facing external competition driven by the entrance of new players in the market, will be able to increase their competitiveness in the global marketplace thanks to a broader raw material selection and a different fuel mix which will also help meeting EU climate change policy for a better and cleaner future.

This document was written to give an overview of the current digital readiness level of the RETROFEED partner and to put into perspective the work that the consortium will perform during the project to increase and improve energy intensive but key industrial processes.

9 REFERENCES

[1] PWC 2020: Digital Factories 2020: Shaping the future of Manufacturing. https://www.pwc.de/de/digitale-transformation/digital-factories-2020-shaping-the-future-of-manufacturing.pdf