

D4.1

Characterisation of demo sites

STAM

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This project has used a standard methodology already developed in the eLITHE (Grant Agreement number: 101138325), following EU recommendations. Ad hoc modifications were added to comply with the conditions of the Grant Agreement for JOULIA (Grant Agreement number: 101192555).

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Abbreviations

Table 1: Abbreviations

aFRR	Automatic Frequency Restoration Reserve
AC	Alternating Current
AGC	Automatic Generation Control
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
DER	Distributed Energy Resources
DG	Distributed Generation
EMC	Electromagnetic Compatibility
FCR	Frequency Containment Reserve
FSM	Frequency Sensitive Mode
LC	Inductance-Capacitance

mFRR	Manual Frequency Restoration Reserve
MARI	Manually Activated Reserves Initiative
PFD	Process Flow Diagram
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
PPA	Power Purchase Agreement
PV	Photovoltaic
P&ID	Piping and Instrumentation Diagram
RES	Renewable Energy Sources
TSO	Transmission System Operator
UC	Use Case
VPP	Virtual Power Plant

Executive Summary

This document is the deliverable “**D4.1 – Characterisation of demo sites**” of the JOULIA project (Electrification of industrial processes using induction and microwave technologies) and is part of Work Package 4 “Baseline assessment and requirements definition”, responsible mainly for the **characterisation of the existing processes** and the establishment of KPIs.

This report is structured in **three chapters**:

- **Introduction**, which includes the scope, purpose and methodology of the work carried out, as well as the contributions from the partners involved and the correlation with other activities of the project.
- **Demonstrators’ characterisation**, where the two industrial processes addressed by the project are described. It is composed of two sections: the first one illustrates the rubber vulcanisation process in ART, currently based on diathermic oil heating, while the second one presents the glue thermal activation in KFLEX, performed through an electric induction system.
- **Energy and ancillary services markets landscape**, which is composed of the overview of the existing services markets products in Europe and the assessment of extended monetisation potential from pilot ecosystems.

The activities performed in Task 4.1 will enhance the partners to better understand the two demonstrators involved in the project, with focus on their production processes and their needs, which is crucial particularly for the technology developers of the two JOULIA innovative solutions. In general, WP4 aims to set the basis for the project advancement.

1. Introduction

1.1 Scope and purpose

The present report is the deliverable “D4.1 – Characterisation of demo sites” and represents the main result of Task 4.1 “Analysis of use cases and definition of main system requirements, functionalities and flexibility”, collocated within WP4, “Baseline assessment and requirements definition”. This Work Package aims to set the baseline for the project execution, analysing the two demo-sites to collect all the information needed, to define key performance indicators and to assess which data sets are missing or require new instrumentation for gathering more accurate information.

In this context, the main objectives of T4.1 have been:

- To define and collect key information for the JOULIA solutions;
- To set the baseline in the two demo-sites (material and energy flows, energy demand, characteristics of the targeted processes, etc.);
- To analyse the potential of JOULIA technologies in the provision of energy and ancillary services.

1.2 Methodology

Task 4.1, led by STAM, started in M1, ended in M12 and was composed of two core activities, which were carried out in parallel. The first one was the definition of the baseline in the demo-sites and was guided by STAM, while the other one consisted in the analysis of the energy and ancillary services markets landscape and their expected development and was performed mainly by EDP.

The methodology adopted for the first activity can be described through the following steps:

- Set-up of a common template for data collection from demo sites
- Alignment with UNIGE, leader of T7.1, to integrate additional requests and develop a more comprehensive questionnaire
- On-line sessions with demo leaders to present the document, focusing on clarifying unclear requests
- Completion of the document by the demo leaders
- Further iterations where necessary
- Transfer and reorganisation of the collected information into D4.1, including integration where needed
- Fine tuning of the document and deliverable completion

The questionnaire, created by STAM and shared with the demo leaders, asked for information, data, schemes and pictures, including different levels of focus, from the plants overview to the equipment retrofitted within JOULIA.

Furthermore, two on-site visits in ART took place during the task execution. They proved crucial for observing and better understanding the layout and the functioning of the rotocure, i.e., a Rotary Curing Press, as well as the flooring rubber production process.

To analyse the European energy and balancing markets landscape, and project their evolution towards inclusiveness and opening to aggregated distributed energy resources (DER) and demand-side flexibility, a structured methodology is adopted and aligned with reference standards.

Comprehensive Market Scan

An extended review of current market frameworks and anticipated developments is conducted, focusing on products that enable participation by aggregated DER and demand-side flexibility.

Reference: ENTSO-E Balancing Market Design, EU Network Codes, and IEC 62325 – market communication standards.

Technical and Operational Alignment

The compatibility between JOULIA’s Pilot Ecosystems and market requirements is assessed, including prequalification conditions and service provision constraints.

Reference: European Network Code on Electricity Balancing and its Electricity Balancing Guidelines, the FCR cooperation, the Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation – PICASSO – and the Manually activated Reserves Initiative – MARI.

Balancing Market Assessment

A dedicated methodology evaluated European balancing products (e.g., FCR, aFRR, mFRR), identifying those most relevant for DER and flexibility aggregation.

Reference: ENTSO-E Balancing Guidelines and EU Electricity Balancing Regulation.

Monetisation Potential Analysis

Based on the market scan and the compatibility assessment advanced, the extended monetisation potential of Pilot Ecosystems under evolving market conditions was balanced, considering both energy cost savings and balancing service revenues.

Case Study Mapping

The final step mapped a practical use case to illustrate how DER can unlock new revenue streams in line with future market opportunities.

Reference: IEC 62559 – Use Case Methodology – and SGAM – Smart Grid Architecture Model.

1.3 Contribution from partners

Table 2: Contribution table

Partner	Contribution
1. CIRCE	Project coordinator. Deliverable quality reviewer.
2. ART	Demonstrator I. Data and information provider.
3. SIMIC	Technical support.
3.1. SIML	Technical support.
4. STAM	Task leader. Deliverable writer.

5. KFLEX	Demonstrator II. Data and information provider.
6. CEI	Technical support.
7. KTH	Technical support.
8. EDP	Leader of the analysis of energy and ancillary services markets. Deliverable reviewer.
11. UNIGE	Support in the creation of data collection template.
12. CERTH	Support in the creation of data collection template.
13. ISQ	Support in the creation of data collection template.

1.4 Relation to other project activity table

Table 3: Relation to other project activities

Task	Relation to other project activities
T5.1 - Conceptual design	The description of the flooring rubber vulcanisation process (paragraph 2.1.2) provides inputs to T5.1, finalised to the design of the multiphase induction heating system.
T6.1 - Conceptual design	The description of the glue thermal activation process (paragraph 2.2.2) provides inputs to T6.1, finalised to the design of the microwave heating system.
T7.1 - System for process flexibility management and exploitation	The analysis of the energy and ancillary services markets landscape, reported in Chapter 3, provides inputs to T7.1, which develops a digital tool finalised to the assessment of the new heating systems flexibility.

2. Demonstrators' characterisation

2.1 Artigo S.p.A. (ART)

ART has been part of the Mondo Group since 1992, a leading worldwide manufacturer and supplier in the flooring sector. In 1996, the company moved from Milano, where it was founded during the 1960s as a part of the Pirelli Group and settled in Cairo Montenotte (Savona, Liguria). ART produces and commercialises high-performance flooring products for several different sectors, such as schools, hospitals and airports.

2.1.1 Overview of Energy and Production Characteristics

ART facility has an annual¹ production capacity of around 1.3 million m² of finished product.

The energy consumption of the plant consists of:

- ~ 6.5 GWh/y of electricity, slightly covered by the installed PV plant production;
- ~ 300,000 Sm³/y of natural gas, used for both process and space heating.

The PV plant on site underwent repowering and revamping in 2024, reaching a nominal capacity of around 1.6 MW, and it is now expected to generate nearly 2 GWh of electrical energy per year.

Natural gas consumption is used in the diathermic oil heat generators.

2.1.2 The Flooring Rubber Vulcanisation Process

The core of the rubber flooring production is the vulcanisation. This process takes place continuously through the use of a rotocure, a machine specifically designed for the continuous vulcanisation of rubber flooring. The rotocure consists of four main drums:

1. Lower drum
2. Main drum
3. Upper drum
4. Tensioning drum

A metal belt wraps around all four cylinders, as shown in Figure 1.

The uncured rubber flooring is conveyed and vulcanised by moving along this metal belt.

The flooring sheet enters the machine on the metal belt above the lower drum, then moves toward the main drum. At this stage, the material is pressed between the metal belt and the main drum.

The vulcanisation occurs along approximately two-thirds of the circumference of the central cylinder, where heat and pressure act on the rubber. The quality of the vulcanisation process depends on three key parameters: temperature, pressure, time. These parameters are adjusted according to the thickness of the flooring, which typically ranges between 2 and 5 mm. In general, a greater thickness requires longer curing times or slightly higher temperatures to ensure complete and uniform vulcanisation.

¹ All data are related to the year 2024

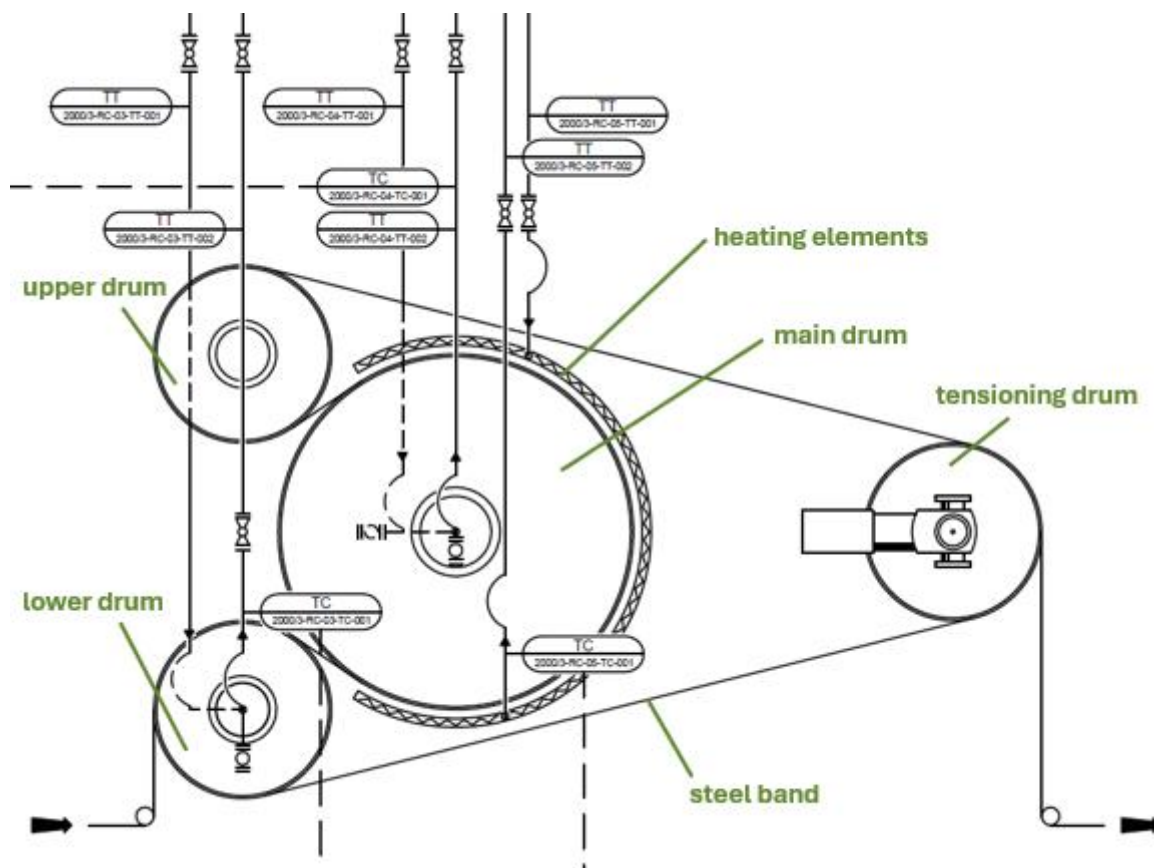


Figure 1: Scheme of the rotocure of the line 2000/3

The lower drum and the main drum are heated with the diathermic oil, while the heating elements can be heated up electrically or by diathermic oil too. In Table 4, the working temperature, measured at the exit of each component, and the power absorbed are reported. The power and the temperatures are thickness dependent.

Table 4: Working parameters for the vulcanisation of a 3 mm floor

Component	Working temperature	Power absorbed
Lower drum	100-125 °C	~50 kW
Main drum	170-180 °C	~100 kW
Heating elements	200-220 °C	~65 kW

Overall, the dwell time of the rubber sheet inside the rotocure is between 5 and 8 minutes, accordingly with the speed of the belt.

In Figure 2, is shown the P&ID of the rotocure, which includes the loops of diathermic oil for all the heated components of the machine. They are connected to a manifold (hydraulic compensator), which receives

the hot oil from the boiler room (at around 250 °C) and sends it back at a temperature 10-15 °C lower. The oil flowing in the three loops connected to the manifold is recirculated and regulated using three-way valves, which receive the working temperature of the oil exiting from each component and compare it to the set point value.

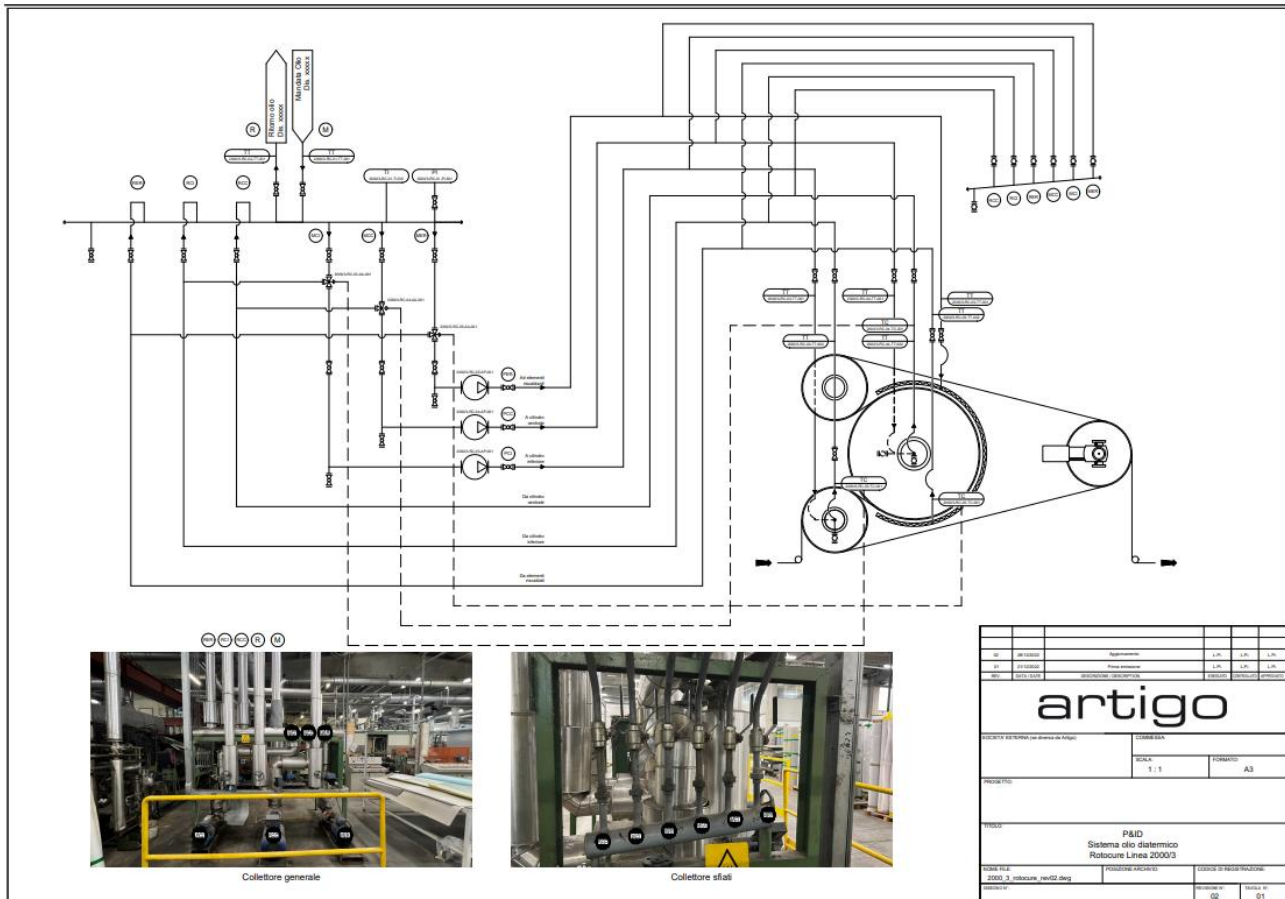


Figure 2: Rotocure, diathermic oil system - P&ID

2.1.3 Existing Monitoring System

ART has developed a monitoring system for the recording of process parameters of the three rotocures. It measures data such as temperatures, pressures, and speed minute by minute and records them. In Figure 3, a screenshot of the current interface is reported.

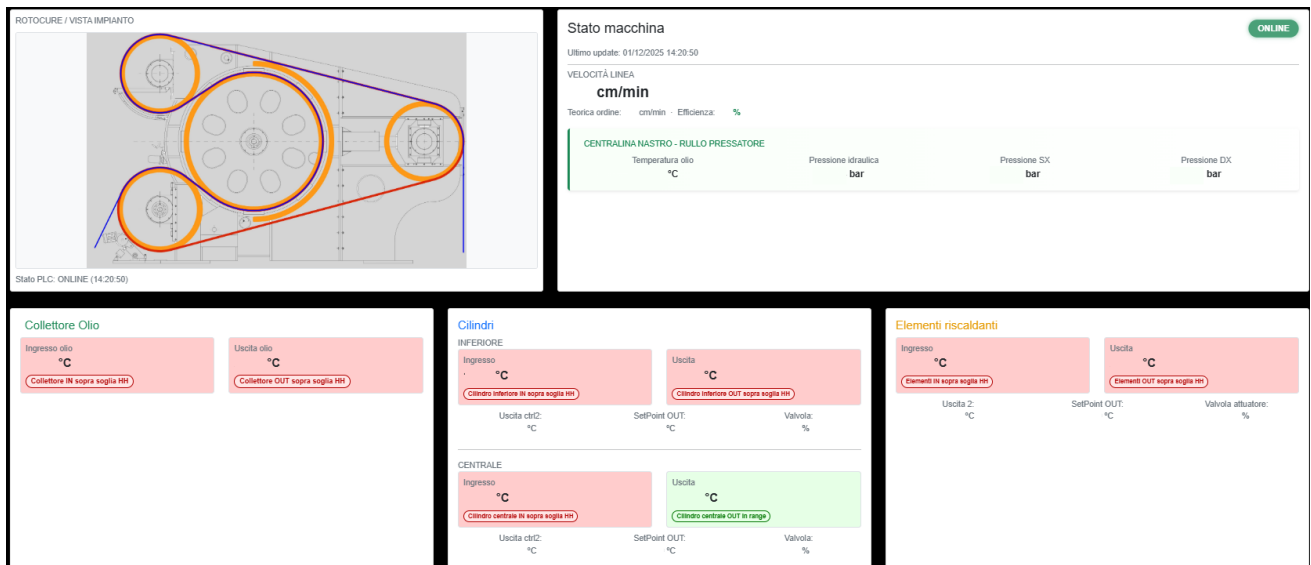


Figure 3: Interface of the monitoring system developed by ART

Lower drum

- Diathermic oil inlet temperature (°C)
- Diathermic oil outlet temperature (two thermocouples) (°C)
- Diathermic oil outlet temperature set point (°C)
- Regulation valve position (%)

Main drum

- Diathermic oil inlet temperature (°C)
- Diathermic oil outlet temperature (two thermocouples) (°C)
- Diathermic oil outlet temperature set point (°C)
- Regulation valve position (%)

Heating elements

- Diathermic oil inlet temperature (°C)
- Diathermic oil outlet temperature (two thermocouples) (°C)
- Diathermic oil outlet temperature set point (°C)
- Regulation valve position (%)

Manifold

- Diathermic oil inlet temperature (°C)
- Diathermic oil outlet temperature (°C)

Hydraulic unit

- Tensioning drum pressure (bar)
- Pushing roller pressures (left and right) (bar)
- Oil temperature

In addition, the speed of the rotocure is monitored.

There is no measurement of the diathermic flow rate, but this parameter can be monitored through a dedicated measurement campaign using a portable flow rate instrument (FLEXIM G601).

2.2 K-FLEX Polska Spolka Ograniczona Odpowiedzialnoscia (KFLEX)

KFLEX, situated in Uniejów, Łódź (Poland), is a multinational manufacturing company specialised in the production of thermal and acoustic flexible elastomeric insulation materials. The company has production facilities and a network of subsidiaries around the globe, in order to provide its products and services to customers wherever they are in the world.

2.2.1 Overview of Energy and Production Characteristics

The main products of KFLEX are reported in Table 5:

Table 5: KFLEX annual production

Type of product	Annual ² production
FEF pipe	59,852,350.54 m
FEF sheet	7,765,475.33 m ²
PE pipe	75,995,503.26 m
High mass sheet	341,214.19 m ²
Multilayer pipes	31,284,231 m

The facility has an annual electrical demand of around 26 GWh and disposes of a 1.5 MW PV Plant. During 2024, it generated 386 MWh; however, its installation was completed at the end of the summer, limiting its production to the last months of the year. The natural gas demand is about 15 GWh.

Currently, two new RES power plants are under construction: a 2 MW PV plant and a 300 kW solar thermal park.

2.2.2 The Glue Thermal Activation Process

The project focuses on the production process of multilayered plastic insulation pipes PERT II, shown in Figure 4. PERT II is a type II polyethylene with enhanced temperature properties, capable of operating at temperatures of up to 95°C. PERT is structured like a woolen collar, strong and difficult to break but flexible.

² All data are related to the year 2024

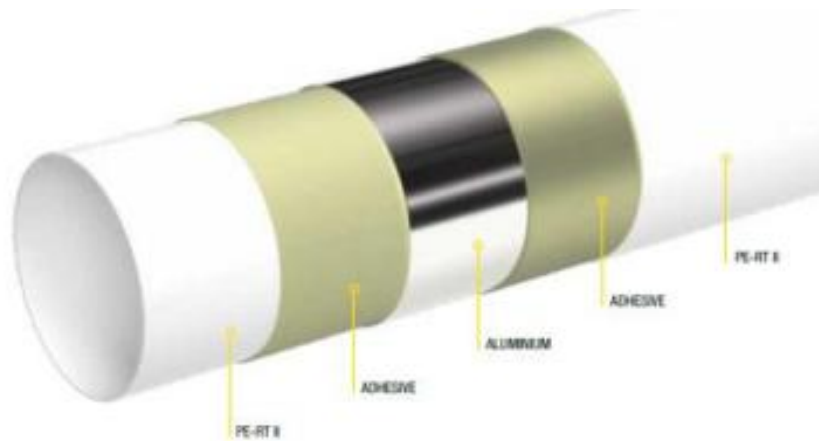


Figure 4: Structure of multilayered plastic insulation pipes PERT II

The PERT II production process is presented in Figure 5, through a PFD.

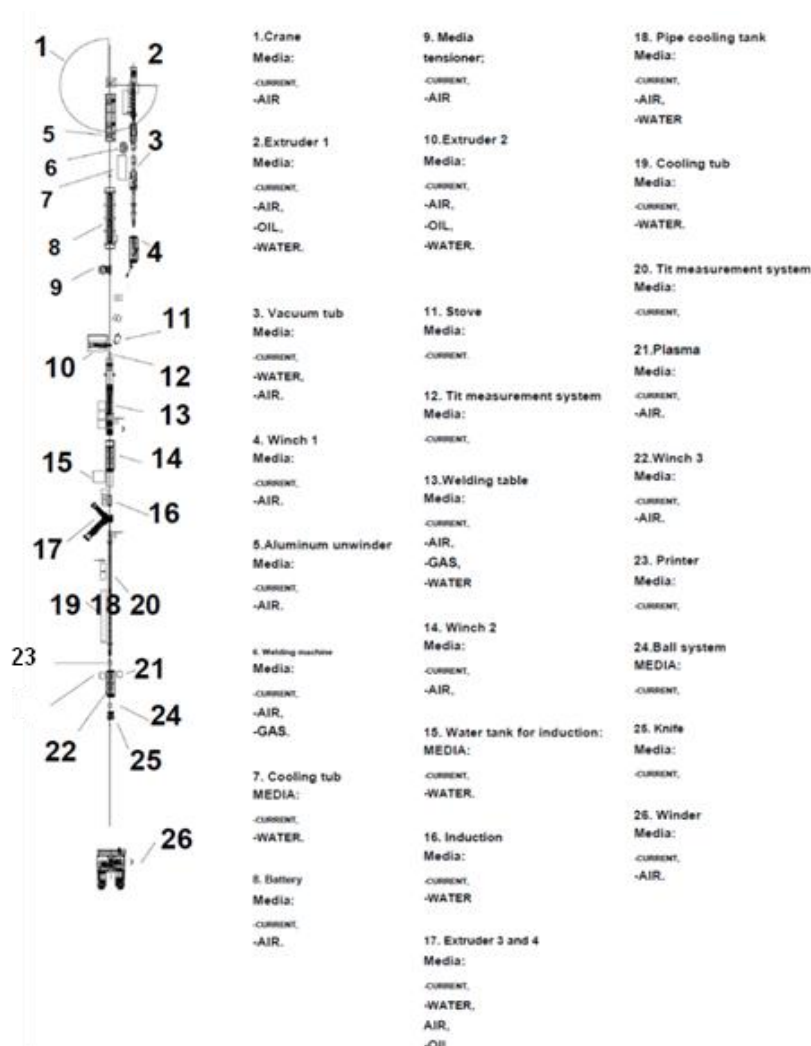


Figure 5: PFD of PERT II production process

The process starts with the internal layer extrusion, which is stabilised before the glue application. Once the glue wraps the inner layer, the pipe is coated with aluminium, butt welded and then covered with glue and overlaid with PERT. After all these steps, all layers are placed, and, with the stabilisation of the pipe, the process is finished.

The glue thermal activation process requires temperatures up to 100 °C, 24h/day, provided through an electric induction system, which leads to a daily consumption of about 1.5 MWh/day. This step occurs immediately after the welding of the aluminium and before the extrusion of the second layer of glue and external pipe, as shown in Figure 5, (step 16). A proper glue activation is essential to ensure pipe quality (at least 15 N/cm resistance force), which is checked via quality control inspection, carried out according to EN ISO 17454_2006.

The heating system is designed for continuous heating of pipes with a diameter of 16 to 32 mm and a wall thickness of 2 mm (for the pipes with a 16- or 20-mm diameter) or 3 mm (for the pipes with a 26- or 32-mm diameter), with a target pipe production speed between 10 and 30 m/min. In Table 6, the technical characteristics of the system are reported.

Table 6: Technical characteristics of the electric induction system currently used for the glue thermal activation

Parameter	Value
Active power	25 kW
Nominal connection power	30 kVA
Supply voltage	3x400 V
Frequency	50 Hz
Cooling water consumption ($t_{\text{water}}=18 - 30\text{ }^{\circ}\text{C}$, $p=0.3 - 0.5\text{ MPa}$)	22 l/min
Dimensions	700×600×800 mm
Weight	200 kg

The heating induction system, shown in Figure 6, consists of a generator cabinet (1) mounted on a stand (2). The stand also houses a roller with an encoder (3) that measures the speed of the tube through the exciter (4).

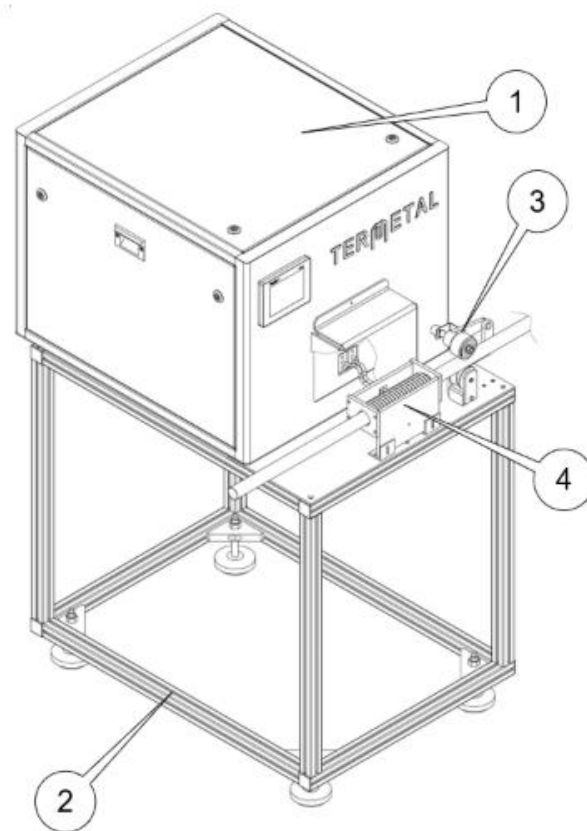


Figure 6: Structure of the heating induction system

The cabinet-type generator is composed by a diode rectifier, smoothing choke, capacitor charging circuit, single-phase transistor inverter, and the related control, protection, and measurement circuits. It also includes an external exciter.

The supply voltage is fed to the rectifier input. It is a six-pulse three-phase diode rectifier with an LC filter at the output. A circuit breaker with an overcurrent release is installed in the rectifier power supply circuit to protect the generator circuits against the effects of short circuits.

The rectified voltage from the bridge output is fed through a choke to a capacitor bank, which supplies power to the transistor inverter generating single-phase AC voltage. A resistor–contactor circuit is included to limit the charging current and allow gentle charging of the capacitor bank.

An EMC filter is also installed in the main power supply circuit to protect the power supply network from electromagnetic interference generated in the inverter.

The inverter is designed as a single-phase resonant voltage inverter. During operation, pairs of half-bridge transistors are switched alternately, causing the load voltage to reverse cyclically.

The inverter supplies power to the exciter via a matching transformer, which, together with the capacitors on the primary side of the transformer, forms a resonance circuit. The operating frequency of the inverter will be close to the resonance frequency of the exciter-capacitor system.

The inverter starts at a frequency several kHz higher than the resonance frequency and gradually reduces it, stopping at a frequency several percent higher than the resonance frequency. This results in a smooth

increase in the power of the device to the set parameters. The power change is achieved by changing the output current set by the programmable device controller.

The generator's electronic control circuits are implemented on printed circuits mounted inside the heater cabinet.

The cooling system dissipates heat generated by individual heater components, such as power electronic semiconductor components, capacitors, output transformers, and exciters. It is built inside the cabinet and consists of an inlet and outlet manifold, a transistor cooler, a diode rectifier cooler, a water-air heat exchanger, and various water fittings and plastic hoses connecting the individual circuits to the manifolds. Outside the cabinet, there are hose ends, the inlet connection being equipped with a mesh filter.

2.2.3 Existing Monitoring System

Energy consumption is generally monitored at a global level, with only some production lines provided with a dedicated power meter. Currently, there is not a system monitoring energy consumption by individual components, but it is estimated by dividing plant's demand by the number of production lines present. However, KFLEX intends to install sensors able to measure energy consumption per component and communicate with an internal software system.

3. Energy and ancillary services markets landscape

3.1 Scan of European energy and balancing products

The European power market typically consists of two main dimensions: wholesale, focused on energy procurement and trading across multiple timeframes, and balancing, focused on ancillary services procurement and settlement, also across multiple timeframes. These dimensions span different horizons – from long-term to real-time – each targeting distinct objectives.

Wholesale markets begin by targeting generation and consumption through baseload contracts and Power Purchase Agreements (PPAs), followed by imbalance minimisation in day-ahead and intraday sessions. Balancing markets initially focus on securing capacity and strategic reserves, while day-ahead and intraday sessions aim to procure and settle capacity and balancing energy for ancillary services, which will be activated in real-time if needed.

Long-term wholesale involves trading energy commodities for future delivery at pre-agreed prices and terms. For example, when a unit hedges or sells a certain capacity for future delivery, part of its revenue is secured upfront. Since forward markets are less liquid than short-term ones, energy is typically sold in smaller blocks – yearly, quarterly, or monthly baseloads and PPAs. Over time, positions are built until the unit is fully or sufficiently hedged, while still allowing optimisation in short-term markets.

Long-term balancing mechanisms are market-based systems designed to secure sufficient resources to maintain supply-demand balance over extended periods (months to years). These markets complement short-term balancing by providing financial and operational certainty for flexible resources such as energy storage, demand response, and dispatchable generation.

The day-ahead market encompasses both wholesale and balancing activities.

At the wholesale participants aim to mitigate imbalance risks, as they now have a clearer view of market conditions and reference their long-term positions. As generation and consumption patterns become more predictable, the gap between physical and traded profiles narrows. At this stage, if a unit's total capacity is sold, it is considered "fully hedged". However, even fully hedged units can participate in day-ahead and ancillary services markets to optimise their physical position and generate additional value.

The buyback process – repurchasing capacity at a lower price – is not always strategic; if a unit cannot meet its sold commitments, it may need to buy capacity from third parties to avoid penalties.

Market clearing is based on aggregated demand and supply curves for each hour of the following day. Sell bids are ranked by merit order, favouring the lowest marginal cost. The market clearing price – spot price – is set at the intersection of these curves, and all dispatched units are paid this price regardless of their original bid.

Participants also offer ancillary services in day-ahead balancing markets. Reserve products vary mainly by activation time, dynamic response, and duration. Common products include:

- Frequency Containment Reserve (FCR)
- automatic Frequency Restoration Reserve (aFRR)

- manual Frequency Restoration Reserve (mFRR)

Transmission System Operators (TSOs) procure reserves to ensure sufficient capacity for activation and imbalance correction. Reserve requirements are estimated using historical, stochastic, and probabilistic data, considering factors such as renewable output and demand profiles. The resulting capacity needs form the basis of procurement tenders.

When imbalances occur, aFRR is triggered automatically to correct them. If fluctuations persist and aFRR cannot keep up, mFRR is activated manually to restore balance.

Day-ahead reserve auctions typically occur before wholesale auctions, meaning reserve commitments may require adjustments to long-term positions. If a player's long-term position cannot support its reserve obligations, it must modify its day-ahead position by buying back capacity.

Intraday trading allows continuous auctions, enabling participants to manage deviations from day-ahead schedules and capitalise on price volatility.

Reserved capacity from day-ahead cannot be resold in later wholesale sessions. Capacity is compensated for availability, while energy is remunerated only upon activation. Balancing bids are ranked by price-based merit order, and real-time activation follows this ranking.

If a capacity bid clears in day-ahead, the provider must submit an energy bid of equal or greater value in the corresponding energy auction. If the capacity bid does not clear, the provider may still participate in intraday balancing energy markets.

The real-time market is the final phase, where TSOs activate ancillary services as needed. From a wholesale perspective, real-time trading is less significant, although some countries (e.g., Netherlands, Belgium, UK) allow imbalance chasing. In these markets, participants may deliberately create imbalances that help the system, earning compensation. If an imbalance aligns with the system's overall imbalance direction, it is rewarded; otherwise, it is penalised. While this principle exists across Europe, deliberate imbalance chasing is prohibited in most countries.

3.1.1 Characterisation of relevant market products

In this section, the most prominent balancing services across Europe and their associated market products are briefly characterised. The analysis focuses on containment and restoration reserve services, as other services – such as replacement reserve, voltage control, and black start – are either exclusive to generators or significantly restrict the participation of aggregators, Virtual Power Plants (VPPs), and Distributed Energy Resources (DERs).

Frequency Containment Reserve (FCR)

FCR, or primary frequency control, is the first frequency response to imbalances. FCR implies an automatic and decentralised response from service providers, meaning each asset should constantly measure grid frequency and react without TSO interference. FCR markets operate through daily auctions. It is a capacity-only market, with daily auctions, held one day before delivery and structured into six 4-hour symmetric blocks for the next day.

automatic Frequency Restoration Reserve (aFRR)

aFRR replaced the secondary reserve and is activated to restore the frequency and the interchanges following an imbalance. While primary control limits and stops frequency excursions, secondary control brings the frequency back to its target value. aFRR is a market product that includes both, capacity and

energy markets. The capacity market auctions close on the day before (D-1), while the energy market operates closer to real-time, with activation based on grid needs. Activation is automatically, triggered by TSO signal, within 5 minutes of a frequency deviation.

manual Frequency Restoration Reserve (mFRR)

mFRR is activated to restore the primary and secondary frequency control reserves, manage congestions, and bring frequency and interchanges back to their target value whenever the secondary frequency control is unable achieve it. mFRR is also a market product including capacity and energy markets. Energy activation is manual and typically happens closer to real-time. Acts as a tertiary reserve, supporting or replacing aFRR if imbalances persist.

The following table summarises the relevant market products highlighted and their main characteristics, as introduced by the European Network Code on Electricity Balancing.

Table 7: Characterising balancing market products open to demand-side flexibility and DER across Europe [1]

Product	FCR	aFRR (capacity)	aFRR (energy)	mFRR (capacity)	mFRR (energy)
Market	Primary reserve	Secondary reserve		Tertiary reserve	
Purpose	Quickly cope to grid imbalances, limiting frequency deviations	Free exhausted FCR reserves and restore system frequency		Free exhausted aFRR reserves and restore system frequency	
Procurement	Local and cross-border				
Auction/ Agreement	Up to D-1	Up to D-1	25 minutes before delivery period	Up to D-1	25 minutes before delivery period
Typical duration	4 hours	4 hours	15 minutes	4 hours	15 minutes
Activation method	Automated, based on frequency deviations	Automated, based on TSO signal		Manual	
Settlement rule (most common)	Pay-as-cleared	Pay-as-bid	Pay-as-cleared or pay-as-bid	Pay-as-bid	Pay-as-cleared or pay-as-bid
Framework	FCR Cooperation	PICASSO*		MARI**	

Member countries include IT and PL?	Not a member	Both, IT and PL, are operational members	Both, IT and PL, are non-operational members
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* PICASSO – Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation

**MARI – Manually Activated Reserves Initiative

The European framework currently addressing implementation/development of each product and the membership status from the different European countries are also presented. Here, special attention was given the Polish and Italian cases, given the dependency from the JOULIA’s pilot ecosystems, located in these two countries.

3.2 Extended monetisation potential from JOULIA pilot ecosystems

Demand flexibility, driven by increased efficiency and optimised scheduling, is expected to unlock new market opportunities for demand-side assets. Controllable industrial manufacturing processes, when aligned with cost-effective primary energy sources such as distributed RES-based generation, have significant potential to provide system balancing services and participate in ancillary service markets.

Across Europe, balancing markets are increasingly opening to demand-side DERs, which can now be aggregated into Reserve Providing Groups. Products such as containment and restoration reserves – offered as both capacity and energy – are emerging as additional revenue streams for demand-side DERs, enabling extended monetisation. Simplified prequalification and service provision requirements (e.g., reduced minimum bid sizes, dynamic response capability, sustained delivery, linearity, and stability) are reshaping ancillary service markets into more inclusive frameworks, accessible to aggregated Distributed Generation (DG) and storage assets.

Although increased competition is expected to drive prices downward, widespread automation, real-time monitoring, and advanced control systems enable continuous energy management and optimised bidding strategies. These strategies aim to achieve cost savings while capturing non-negligible monetisation potential from the provision of balancing services.

3.2.1 Analysis of technical constraints imposed to DER and compliance requirements for service prequalification and provision

Following the characterisation of market products presented in the previous section, this section outlines the main constraints hindering market and product access, along with the overall prequalification and service provision requirements. These are framed within the specific implementation contexts of the two European countries where JOULIA’s pilot ecosystems are deployed – Italy and Poland – highlighting major constraints and requirements imposed on demand-side resources and DER.

More mature and inclusive market frameworks, as observed in reference countries such as Germany, are also analysed to provide a benchmark and a valid basis for comparison.

3.2.1.1 Italy

FCR Requirements [2]

- *Prequalification: Mandatory with Terna – Italian TSO*
- *Technical criteria:*
 - *Frequency Sensitive Mode (FSM) compliance*
 - *Active power variation: $\pm 5\% \frac{\Delta P}{P_{\max}}$*
 - *Frequency insensitivity: $\sim 10\text{mHz}$*
 - *Initial delay: $\leq 500\text{ms}$ for inverter-based resources*
 - *Full activation within 30 seconds*
 - *Sustained delivery: 15–30 minutes*
 - *Linearity and stability required*
 - *Energy management for limited energy resources*
- *Aggregation: Allowed via Balancing Service Providers (BSPs).*

As an operational member of PICASSO Italy complies with its implementation guidelines, and extensively uses the platform for procurement.

aFRR Requirements [3]

- *Prequalification: BSP registration with Terna*
- *Activation: Automatic via Automatic Generation Control (AGC)*
- *Response Time: Full activation within 5 minutes*
- *Duration: Typically, 15 minutes*
- *Aggregation: Permitted; aggregator responsible for compliance*

Despite being a non-operational member of MARI Italy aligns with its implementation guidelines.

mFRR Requirements [4]

- *Prequalification: BSP registration*
- *Activation: Manual activation by TSO*
- *Response Time: 15 minutes after activation signal*
- *Duration: Up to 2 hours*
- *Aggregation: Allowed*

3.2.1.2 Poland

FCR Requirements

- *Prequalification: With PSE – Polish TSO*

- *Technical Criteria:*
 - *FSM compliance*
 - *±5% active power range*
 - *Insensitivity: ~10mHz*
 - *Initial delay: ≤500ms*
 - *Activation: 30 seconds*
 - *Sustained delivery: 15–30 minutes*
- *Aggregation: Allowed via BSPs.*

As an operational member of PICASSO, Poland complies with its implementation guidelines and uses the platform for procurement.

aFRR Requirements [3]

- *Activation: Automatic via AGC*
- *Response Time: Full activation within 5 minutes*
- *Duration: 15 minutes*
- *Aggregation: Permitted*

Despite being a non-operational member of MARI, Poland aligns with its implementation guidelines.

mFRR Requirements [4]

- *Activation: Manual*
- *Response Time: 15 minutes*
- *Duration: Up to 2 hours*
- *Aggregation: Allowed*

3.2.1.3 Germany

FCR Requirements

- *Prequalification: With German TSOs, via common platform*
- *Technical Criteria:*
 - *FSM compliance*
 - *±5% active power range*
 - *Insensitivity: 10 mHz*
 - *Initial delay: ≤500 ms*

- *Activation: 30 seconds*
- *Sustained delivery: 15–30 minutes*
- *Aggregation: Fully enabled, with auctions supporting aggregators, VPPs and DER participation extensively. Together with Ireland, UK, France, Belgium and Switzerland, Germany allows generators, load, pump storage and batteries to qualify as providers*

As an operational member of both, PICASSO and MARI, Germany complies with the respective implementation guidelines and extensively uses the platforms for procurement.

aFRR Requirements [3]

- *Activation: Automatic via AGC*
- *Response Time: Full activation within 5 minutes*
- *Duration: 15 minutes*
- *Aggregation: Strongly supported through market-based procurement. Together with Switzerland, Germany allows generators, load, pump storage and batteries to qualify as providers*

mFRR Requirements [4]

- *Activation: Manual or scheduled*
- *Response Time: 15 minutes*
- *Duration: Up to 2 hours*
- *Aggregation: Fully supported through competitive auctions. Together with Ireland, UK, Belgium, Switzerland and Czechia, Germany allows generators, load, pump storage and batteries to qualify as providers*

Most European countries follow general prequalification, activation, delivery, and aggregation standards aligned with European Network Code on Electricity Balancing and its Electricity Balancing Guidelines. **Germany** leads in flexibility and aggregation, extending the providers pool by allowing generators, load, pump storage and batteries. **Italy** and **Poland** generally align with major EU-level frameworks, also introducing local adaptations to its implementation.

3.2.2 Assessment of unlocked revenue opportunities

JOULIA project is primarily focused on the decarbonisation of process industries and energy-Intensive industries through electrification, particularly for heat applications used in manufacturing processes. Electrifying industrial processes aims to reduce emissions, decrease dependency on fossil fuels, and enable the progressive integration of Renewable Energy Sources (RES) into manufacturing.

The industrial segments targeted by JOULIA's pilot ecosystems include rubber and plastics manufacturing, while food production and ceramics manufacturing are considered as follow-up replication cases.

The two technologies explored – induction and microwave heating – are highly efficient electromagnetic heating systems suitable for medium-range temperatures (between 100°C and 500°C). These aim to fully electrify two targeted industrial processes: rubber vulcanisation and multilayer pipe adhesive activation, while improving the efficiency of these medium-temperature processes. Rubber vulcanisation relies on rotary drums and a conveyor belt (reference temperature: 180°C), whereas multilayer pipe adhesive activation uses an extrusion machine (reference temperature: 100°C).

3.2.2.1 Introduction to JOULIA's pilot ecosystems

Pilot #1 – Induction heating for rubber vulcanisation

Site: Artigo, Cairo Montenotte, Savona, Italy

Vulcanisation applied to the production of elastomeric materials, such as rubber, is a key process requiring heat with a suitable and uniform profile to achieve the desired mechanical and tribological properties.

State-of-the-art heating systems used in standard vulcanisation processes are highly dependent on fossil-based energy. Used due to the stable heat profiles delivered, which implies to achieve and maintain the highest temperature needed, limited modularity and high heat losses lead to high inefficiency, as the productive process is composed by different steps, each requiring specific temperature profiles.

A key challenge remains, obtain more efficient systems achieved through an even heat distribution.

Within JOULIA, a prototype concept based on an innovative multiphase induction heating system will be scaled up, aiming at preventing undesired heating and efficiency losses once proper thermal profile management is implemented.

Objectives:

- *Enable a flexible use of electricity required in the vulcanisation process, controlling the induction heating system energy consumption and coupling it with locally available PV output, maximising RES-based self-consumption and minimising grid energy imports, while valuing demand flexibility in energy and ancillary service markets*

Overview:

Electricity consumption

- *Pilot-site electricity consumption: ~6.5 GWh/year*
 - ~5.7 GWh/year of imported energy
 - ~0.8 GWh/year self-consumed from local PV generation (underperformance of 2024 due to repowering and revamping)
- *Induction heating system electricity consumption: 2.7 GWhEP/year*
 - *Total consumption for the site: 3.60 GWh/year*

Electricity generation

- *Installed RES-based generation: ~1.6 MW*
- *Annual production capacity: ~2 GWh/year*
 - ~75% used for self-consumption

- ~25% injected into the grid

Details of the industrial process

- *Operating hours of the production line: uninterrupted operation between Monday 5 AM and Saturday 5 AM*

Pilot #2 – Microwave heating for multilayer pipe gluing

Site: KFLEX, Uniejow, Lodz, Poland

Given the conductivity from the involved materials, particularly metals, considered as microwave reflectors, thus not absorbing microwaves effectively, there is very limited applications for the use of microwave heating in production processes involving such materials.

Within JOULIA, following a novel application approach, based on specific filtering designing and tuning elements that will adapt the impedance of the applicator, ensuring an optimised heat distribution and also preventing microwave leakage, the absorption of microwave power will be adapted to the speed of the process, allowing for the heating unit to flexibly adapt from 30 up to 100% of the available power range, thus being fully integrated with the processing system.

Objectives:

- *Enable a flexible use of electricity required in the gluing process, managing the microwave heating system energy consumption and optimally scheduling it to avoid high-price periods, performing real-time controllability of the production rate, while valuing demand flexibility in energy and ancillary service markets*

Overview:**Electricity consumption**

- *Pilot-site electricity consumption: ~26 GWh/year*
- *Microwave heating system electricity consumption:*
 - *Multilayer pipe production lines: 220 kWh*
 - *Glue thermal activation process: 1.5 MWh/day*

Electricity generation

- *Installed RES-based generation: 1.50 MWp*
- *Annual production capacity: 386 MWh/year*

Details of the industrial process

- *Operating hours of the production line: uninterrupted 24h operation for both processes, multilayer pipe production and glue thermal activation*

3.2.2.2 Applicable prequalification/service provision requirements [5]

Prequalification and service requirements applicable to Pilot Ecosystem #1 – Italy

- **Balancing process in place:**

A centralised dispatch is implemented. A scheduling and dispatching model where aggregated generation and consumption power and schedules are determined by the TSO within its integrated scheduling process.

- **FCR – capacity:**

- *FCR market product available. Operating reserves are activated for frequency stabilisation after imbalances*
- *The procurement scheme available is mandatory, implying an obligation, from connected generators, to reserve a certain capacity to meet TSO requirements. The price is fixed by the TSO, the National Regulatory Authority, or is free*
- *The product resolution – minimum bid size – is not limited in power, and time limitations – e.g., maximum resolution for which the product can be bid into the market – are not applicable*
- *No time ahead from real time – when actual activation may take place – of the product auction/agreement is applicable*
- *FCR providers are limited to generation units*
- *FCR is a symmetrical product, meaning that upward and downward regulation volume must be equal*
- *No pricing rule for settlement is applicable*
- *No monitoring, in place by the system operator to ensure performance, is applicable*
- *The BSP obligations are not allowed to be transferred to a third party*

- **FCR – energy:**

- *There is no FCR balancing energy market*
- *The pricing rule for settlement – energy [MWh] – is based on a regulated price, set by the relevant regulatory authority*
- *The monitoring in place is ex-post check*

- **aFRR – capacity:**

- *aFRR market product available*
- *The product resolution – limitations in power or time – is no applicable*

- **aFRR – energy:**

- *The procurement scheme available is hybrid, implying a combination of mandatory and market schemes*

- *Free bids are allowed, without a pre-contract for balancing capacity, and the activation rule follows a parallel proportional activation – pro rata*
- *The product resolution is ≤ 1 MW, limited to hourly blocks*
- *Time ahead from real time, when activation takes place, is ≤ 1 minute*
- *The pricing rule for settlement – energy [MWh] – is based on a pay as bid model, with contracted providers getting paid based on their offer price*
- *The monitoring in place is real-time*
- *The activation time for aFRR – from 0 to max, meaning the time between receiving a valid activation setpoint and the end of ramping to meet the setpoint – is between 2 minutes and 5 minutes, $[2\text{min} < x \leq 5\text{min}]$*
- **mFRR – capacity:**
 - *mFRR market product available*
- **mFRR – energy:**
 - *The procurement scheme available is hybrid, implying a combination of mandatory and market schemes*
 - *Free bids are allowed, without a pre-contract for balancing capacity, and the activation rule follows a merit order – ranking offers in ascending order of their marginal costs*
 - *The product resolution is ≤ 1 MW, limited to hourly blocks*
 - *Time ahead from real time, when activation takes place, is between 5 minutes and ≤ 15 minutes, $[5\text{min} < x \leq 15\text{min}]$*
 - *mFRR providers are limited to generation and pump storage units*
 - *The pricing rule for settlement – energy [MWh] – is based on a pay as bid model, with contracted providers getting paid based on their offer price*
 - *Partial activation is possible in both directions, upwards and downwards*
 - *The activation time for mFRR is between 10 minutes and 15 minutes, $[10\text{min} < x \leq 15\text{min}]$*

Prequalification and service requirements applicable to Pilot Ecosystem #2 – Poland

- **Balancing process in place:**

A centralised dispatch is implemented. A scheduling and dispatching model where aggregated generation and consumption power and schedules are determined by the TSO within its integrated scheduling process.

- **FCR – capacity:**
 - *FCR market product available. Operating reserves are activated for frequency stabilisation after imbalances*
 - *The procurement scheme available is hybrid, implying a combination of mandatory and market schemes, where there is no contract obligation for grid users to offer reserve*

capacity. Grid users can voluntarily participate and bid a price/customise its offer (e.g., volume timeframe). The market outcome may lead to bilateral contracts

- The product resolution is $\leq 1\text{MW}$, and time limitations are not applicable
 - No time ahead from real time of the product auction/agreement is applicable
 - FCR providers are limited to generation units
 - FCR is a symmetrical product, meaning that upward and downward regulation volume must be equal
 - The pricing rule for settlement – capacity [MW] – is based on a regulated price, set by the relevant regulatory authority
 - The monitoring in place is hybrid, meaning that combines ex-post check – performance monitoring 24 hours after delivery – and real-time
 - The BSP obligations are not allowed to be transferred to a third party
- **FCR – energy:**
 - The pricing rule for settlement – energy [MWh] – is based on marginal pricing, meaning that all balancing energy is settled at the same price – price of the most expensive capacity bid dispatched, or energy bid activated
 - The Balancing Responsible Party (BRP) or its chosen representative is fully responsible for its imbalances
 - The monitoring in place is hybrid
- **aFRR – capacity:**
 - aFRR market product available
 - The procurement scheme available is hybrid, implying a combination of mandatory and market schemes
 - The product resolution is $\leq 1\text{MW}$, and time limitations are not applicable
 - aFRR providers are limited to generation units
 - aFRR is a symmetrical product
 - The pricing rule for settlement – capacity [MW] – is based on a regulated price, set by the relevant regulatory authority
 - The monitoring in place is hybrid, combining ex-post check and real-time
 - The BSP obligations are not allowed to be transferred to a third party
- **aFRR – energy:**
 - The procurement scheme available is market only, implying that there is no contract obligation for grid users to offer reserve capacity. Grid users can voluntarily participate and bid a price/customise its offer (e.g., volume timeframe). The market outcome may lead to bilateral contracts
 - Free bids are not allowed, and the activation rule follows a merit order, ranking offers in ascending order of their marginal costs
 - The product resolution is $\leq 1\text{MW}$, limited to hourly blocks
 - Time ahead from real time, when activation takes place, is ≤ 1 minute

- *The pricing rule for settlement – energy [MWh] – is based on marginal pricing*
- *The monitoring in place is hybrid*
- *The activation time for aFRR is between 2 minutes and 5 minutes, $[2min < x \leq 5min]$*
- **mFRR – capacity:**
 - *mFRR market product not available*

3.2.2.3 Case study: extended monetisation driven by evolving market opportunities for DER

The heat profiles required by the targeted industrial processes are highly stable, demanding a flat and consistent primary energy consumption, even when electrified using highly efficient electromagnetic heating systems such as induction and microwaves.

Due to the continuous nature of these manufacturing processes, the electricity consumption profile offers limited potential for flexibility, which restricts the ability to provide balancing services through demand-side flexibility alone.

Since the required primary energy consumption profiles exhibit low adaptability to fluctuations in distributed RES-based generation and to market price signals, DER – such as DG combined with Storage – are essential. They enable maximisation of local renewable energy self-consumption and unlock alternative revenue streams from balancing services provision, without disrupting manufacturing operations.

The extended monetisation potential of the pilot ecosystems under analysis is framed by the following Use Case (UC), primarily targeting self-consumption maximisation and balancing services provision through locally available DG + Storage.

UC: Optimised DER dispatch scheduling for energy costs saving and balancing services revenue maximisation

The proposed UC aims at maximising the energy costs savings and the revenues from balancing services provision by optimising the scheduling of DER – DG, storage and demand-flexibility – through self-consumption, time-of-use, and capacity/energy dispatching for containment and restoration reserve provision.

Objective

- *Maximise energy cost savings and revenues from service provision*

The aim is to use available DG and storage capacity to perform optimal scheduling of charge/discharge cycles and energy management, targeting the maximization of self-consumption during high energy price periods, maximizing cost savings, and dispatch DG and/or storage capacity for balancing services provision when capacity/energy containment/restoration reserve prices are high, maximizing service provision revenues

Optimisation strategy

- *Continuously evaluate:*

- *Current and future energy prices (from active PPAs or wholesale market)*
- *Settlement prices for balancing market products (marginal or regulated prices applied to containment and restoration reserve capacity and energy)*
- *Determine the most cost-effective operational mode based on these evaluations*

Operational logic

Scenario 1: if energy price from PPAs/wholesale > expected capacity/energy price for balancing services

➔ *Self-consumption maximisation and surplus generation storage should be prioritised*

Scenario 2: if energy price from PPAs/wholesale < expected capacity/energy price for balancing services

➔ *Available DG + Storage capacity should be dispatched*

Market interaction

- *Balancing market settlements occur ahead of delivery, based on confirmed dispatch/activation outcomes*
- *Upon confirmation, DG + Storage capacity can be repurposed to optimise performance and revenue streams*

Relevant constraints

- *Storage capacity limits*
- *DG availability*
- *Market activation commitments*

Modelling approach

- *Linear or Mixed-Integer Linear Programming for scheduling*
- *Inputs: price forecasts, load forecasts, generation forecasts*
- *Outputs: dispatch schedule for DG and storage*

Main considerations

- *Forecast accuracy: price and generation forecasts must be reliable*
- *Market rules: balancing services often require prequalification and firm commitments*
- *System response: storage and DG must meet activation times – e.g., FCR, aFRR*

General UC diagram

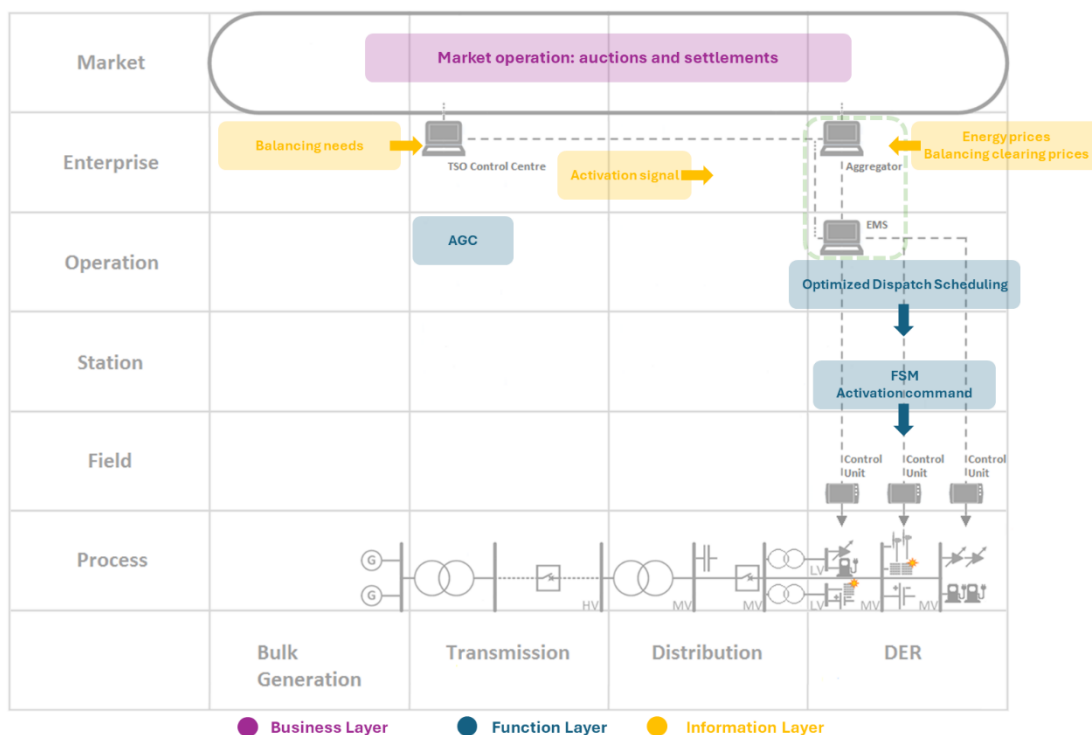


Figure 7: Diagram of the UC

The proposed UC diagram is aligned with the integration profile, high-level process and data flow proposed by the IEC 62559 methodology and mapped according to the Smart Grid Architecture Model – SGAM.

3.3 Expected market evolution driving demand-side flexibility

As market-based procurement for DER – including demand-side flexibility, DG, and storage – progresses slowly, system operators are establishing rules for ownership, management, operation, and market participation of these assets. A non-discriminatory framework is under development to enable widespread participation of DER in multiple market mechanisms by granting inclusive access to different market products, including balancing services.

Despite these efforts, progress across Europe remains uneven. Price signals and dynamic electricity pricing contracts are still largely inaccessible to end-users, particularly citizen energy communities.

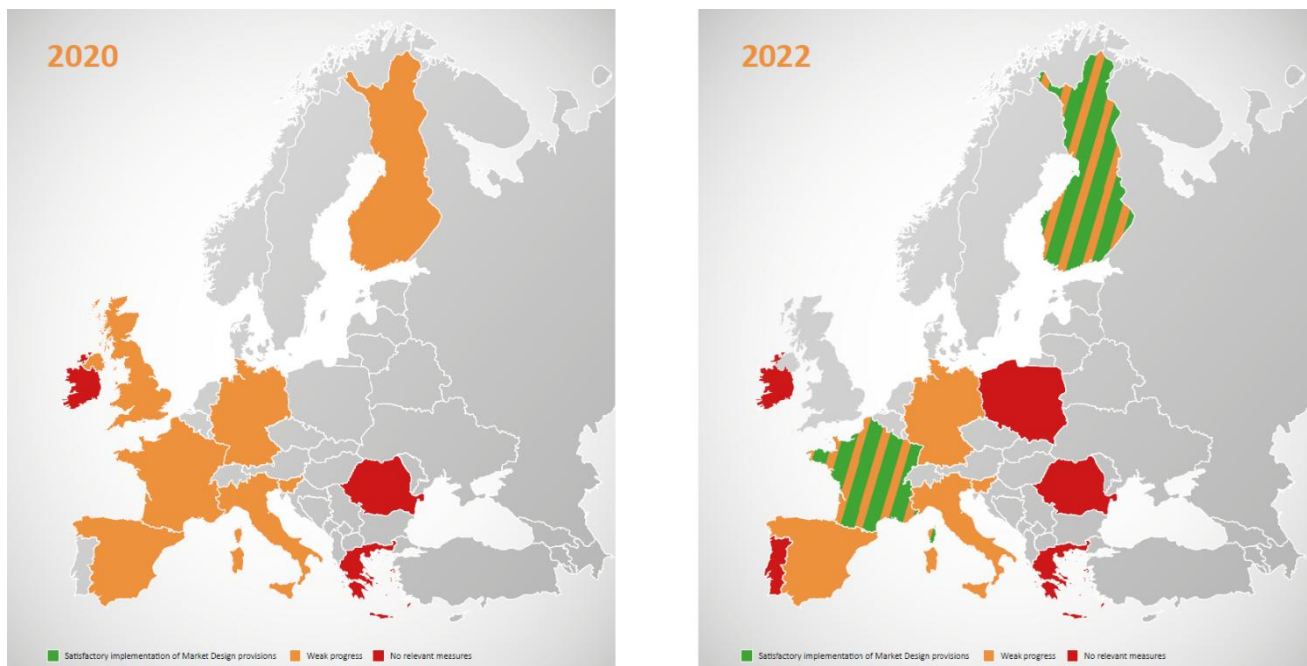


Figure 8: Mapping the progress in implementing market designs driving demand-side flexibility adoption across Europe [6]

The review of recent progress in implementing key measures for demand-side flexibility inclusion focused on the following, from [6]:

- Market-based procurement of all DER by System Operators
Finland and France are leading the way by incentivising system operators to procure flexibility through market-based procedures, regulating non-discriminatory access to relevant system data, and promoting market-based procurement of DER
- Non-discriminatory participation of all DER in all markets and mechanisms
France is advancing with capacity mechanisms based on technology-neutral participation requirements. Germany already operates several reserves and interruptibility mechanisms, but technical requirements still limit DER participation. Italy introduced a capacity mechanism theoretically open to DER, but contracted capacity from these assets remains limited due to restrictive participation requirements. Poland launched a capacity market that is nominally technology-neutral, but technical barriers still prevent DER participation

Regarding the non-discriminatory participation of DER, both individually and in aggregated form, in balancing markets:

- *Italy: Implementation faces limitations for RES, storage, and demand flexibility. Currently, only bulk-generation units (>10 MVA) can participate in balancing markets. However, system operators have initiated a pilot project to open balancing markets to decentralised resources, both individually and aggregated*

- *Poland: Demand-side participants can currently only join balancing markets through their energy supplier (retailer). Independent participation is allowed only if they act as their own BRP. Aggregation remains restricted, mainly due to network access limitations, such as the limited number of high-voltage nodes*

Conclusions

This report, **D4.1 “Characterisation of demo sites”**, establishes the **baseline for the development and integration of JOULIA technologies**. Task 4.1, “Analysis of use cases and definition of main system requirements, functionalities and flexibility”, was composed of two main activities, carried out in parallel, and the present document is divided accordingly. Specifically, Chapter 2 describes the industrial processes at the two demo sites targeted by the project, while Chapter 3 focuses on the analysis of the energy and ancillary services markets landscape.

The baseline definition has been carried out through questionnaires and includes data and insights provided by the demo leaders. This activity enabled the consortium to:

- **Characterise the two industrial processes** involved in JOULIA, both qualitatively and quantitatively, including technical diagrams
- Understand the **energy and material flows**, the **working temperatures** and the operational parameters at the two demo sites

In this report, Chapter 2 is divided into two main sections, one for ART and one for KFLEX, both covering the demo overview (plant production, energy consumption, RES plants installed), the targeted process (energy demand profile, working temperatures, etc.), and the monitoring system. The characterisation of **ART flooring rubber production process** focuses on the **vulcanisation phase**, carried out in the **rotocure**, a machine composed of four revolving steel drums encompassed by an endless steel band. Here, the vulcanisation, ruled by three parameters (temperature, pressure, time), takes place due to the heat exiting from the main drum, which works at 170-180 °C, and the heating elements, between 200 and 220 °C. These components, as well as the lower drum (100-125 °C), used for prevulcanisation, are currently heated using diathermic oil. At the second demonstrator, **KFLEX**, the process targeted is the **glue thermal activation** in the **multilayer pipe production**. This is carried out by an **electric induction system**, with a consumption of approximately 1.5 MWh/day.

Chapter 3 presents an overview of the **European energy and ancillary services markets**, which are progressively evolving toward greater integration of demand-side flexibility and distributed energy resources (DER). While wholesale and balancing markets continue to prioritise long-term hedging and system stability, ancillary services are increasingly open to aggregated flexible loads. This shift creates **new monetisation opportunities for electrified industrial processes**. Although the JOULIA pilot sites exhibit stable and continuous heat demand, their coupling with DER such as on-site generation and storage can unlock additional revenue streams without affecting production.

Nevertheless, participation in these markets requires compliance with specific **technical and regulatory conditions**, which differ substantially across Member States. Italy and Poland align with EU frameworks but remain less inclusive toward DER and aggregators, whereas Germany stands out as a benchmark for market openness. Against this background, a **preliminary use case** has been outlined, centred on optimised DER scheduling to maximise self-consumption and allocate available flexibility to balancing services when economically favourable. Overall, the European trend points toward gradually more technology-neutral participation, positioning JOULIA to benefit from emerging flexibility mechanisms through advanced forecasting, optimisation, and control solutions.

To conclude, the **results of this deliverable** will provide **inputs** particularly to:

- **WP5** – Design and engineering of induction system, led by CIRCE, which will use the information and data on rubber vulcanisation process at ART gathered within T4.1;
- **WP6** – Design and engineering of microwave system, led by CEI, which will use the information and data on glue thermal activation process at KFLEX gathered within T4.1;
- **WP7/WP8** – Digital tools for processes optimisation, in particular **T7.1/T8.1** System for process flexibility management and exploitation, led by UNIGE, which will use the analysis of energy and ancillary markets to feed the tool developed for the demo sites flexibility assessment.

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Electrification of industrial processes using induction and microwaves technologies



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@jouliaproject.bsky.social



www.jouliaproject.eu



info@jouliaproject.eu

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