JOULIA

Electrification of industrial processes using induction and microwaves technologies

D4.2

Evaluation Methodology

CERTH

11/2025

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Project Information

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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

General	
CAPEX	Capital Expenditure
EC-KPI	Economic KPI
EMF	Electromagnetic Field
ENV-KPI	Environmental KPI
GHG	Greenhouse Gases
IS	Integrated System
KPI	Key Performance Indicator
LCA	Lifecycle Analysis
NPV	Net Present Value
ONLC	Occupational noise level compliance
OPEX	Operational Expenditure
PE	Primary Energy
PM	Profit Margin
S-KPI	Social KPI
T-KPI	Technical KPI
TERIR	Total Electrical Recordable Incident Rate
WTM	Workplace Temperature Monitoring
Partners	
ART	ARTIGO S.P.A.
CERTH	CENTRE FOR RESEARCH AND TECHNOLOGY, HELLAS
CEI	INNCEINMAT
CIRCE	CIRCE – CENTRO DE INVESTIGACIÓN DE RECURSOS Y CONSUMOS ENERGÉTICOS
CORE	CORE INNOVATION AND TECHNOLOGY OE
ISQ	INSTITUTO DE SOLDADURA E QUALIDADE
K-FLEX	K-FLEX POLSKA SP ZOO
KTH	KUNGLIGA TEKNISKA HOEGSKOLAN
SIMIC	SIMIC S.P.A
UNIGE	UNIVERSITA DEGLI STUDI DI GENOVA
STAM	STAM SRL

Table 1: Abbreviations

Executive Summary

The purpose of this deliverable is to establish a comprehensive framework for the evaluation of innovative induction and microwave heating technologies, by defining **Key Performance Indicators (KPIs)** for **technical, environmental, economic, and social assessment.** The ultimate goal is to evaluate the improvements achieved through the implementation of these two advanced integrated technologies in comparison to conventional heating methods in two industrial processes in two energy-intensive industries:

- **The vulcanization process** in the rubber industry of **ARTIGO S.A. (Italy)**, where the current heating system using **diathermic oil heated by a natural gas burner** will be upgraded to an **induction heating system**,
- **The multilayer pipe gluing process** in the pipe industry of **K-FLEX S.A. (Poland)**, where the current heating system which is based on **water heated by electric heating elements in storage tanks** will be replaced by a **microwave heating system**.

This deliverable initially focuses on the definition of the most appropriate KPIs, which will allow KPIs' owners to conduct a quantitative assessment of the technical, environmental, economic and social impact the new integrated technologies are accompanied with. These KPIs are designed to capture the key differences between the baseline and the upgraded scenarios in each demonstration case, with a focus on aspects such as the overall system performance, energy efficiency, production capacity, Global Warming Potential and working conditions issues. Most of the defined KPIs are common for both integrated technologies, with some targeted KPIs in each technology separately to be established.

Once the KPIs are defined, the key process-driven parameters that directly affect these indicators are identified. These parameters, such as temperature and pressure levels, fossil fuel and electrical energy consumption, system durability etc., will be critical for monitoring accurately the performance of the new technologies in the real industrial environments.

Following the identification of these parameters, the deliverable will also focus on the definition of the necessary sensors' specifications and quantities required to monitor these key process-driven variables in real-time. This includes selecting the appropriate number and types of sensors, to ensure accurate data collection for each demonstration activity and thus to manage to calculate properly the respective KPIs.

By establishing this KPI-based evaluation framework, this deliverable aims to provide a solid foundation for assessing the technical, economic, environmental, and social benefits of the upgraded induction and microwave technologies. The results will not only demonstrate the potential of these innovative solutions to improve overall system performance and reduce CO_2 emissions, but will also support the scalability and wider adoption of them in energy-intensive industries.

1. Introduction

In the realm of industrial innovation, **Key Performance Indicators (KPIs)** are widely used as quantitative metrics for monitoring, evaluating, and improving the performance of processes and technologies. KPIs serve as **critical tools for assessing the impact of new technologies**, allowing the quantification of technical, environmental, economic, and social aspects. In energy-intensive industries, where energy efficiency, energy consumption, and environmental footprint are key concerns, the proper definition and calculation of KPIs are essential for evaluating process performance, identifying weaknesses, and measuring improvements achieved due to the implementation of advanced technological solutions. KPIs can be directly measured, calculated through mathematical formulas, or estimated based on experimental data, depending on the nature of each indicator. Their systematic use not only enhances decision-making processes, but also ensures sustainability and continuous optimization of industrial processes in energy intensive industries.

Several initiatives have introduced various **KPI frameworks** for monitoring and evaluating alternative solutions in industrial processes. However, selecting the most appropriate KPIs, especially as regards industrial processes evaluation, remains a complex and challenging task, as it requires specialized expertise and in-depth knowledge. The identification of the most relevant KPIs to each examined case is a tough procedure which requires critical delimitation of each examined system's boundaries**.** The complexity of this process lies in the fact that retrofitting industrial processes involves multiple interrelated dimensions, making the KPI-based evaluation process both demanding and critical, since on the one hand, the selected KPIs must address the needs of the industry, while on the other hand, they must effectively assess the environmental, social, economic, and technical impact of the upgraded technologies.

To this end, this deliverable aims to **develop a comprehensive framework for the evaluation of the innovative induction and microwave heating technologies** which are introduced in JOULIA project, focusing on their technical, environmental, economic, and social impact. The core objective is to assess the improvements achieved through the implementation of these advanced technologies, compared to conventional heating methods, in two energy-intensive industrial processes:

- The **vulcanization** process in the rubber industry of **ARTIGO S.A.** (Italy), where the current diathermic oil heating system powered by a natural gas burner will be upgraded to an **induction heating system**.
- The **multilayer pipe gluing** process in the pipe industry of **K-FLEX S.A.** (Poland), where the existing water-based heating system with electric heating elements will be replaced by a **microwave heating system**.

In this context, the definition and evaluation of **Key Performance Indicators (KPIs)** play a central role in the assessment process. Through the identification of suitable KPIs, the project aims to quantify the impact of the upgraded technologies in terms of energy efficiency, production performance, CO2 emissions reduction, cost-effectiveness, and social aspects. Additionally, this approach will enable a direct comparison between the baseline and the upgraded scenarios, highlighting the added value of the new integrated technologies in both industries.

To achieve this a specific KPI-based methodology framework has been established, structured in four main steps:

Step 1

The **first step** ensures precise organization regarding sharing the work which has to be done. Hence, the focus was given in the definition of specific working teams by establishing a working team for each KPI category (technical, environmental, economic and social), according to the area of expertise of each partner. This rationale was attended as an initial step to avoid wasting valuable time and efforts during the definition of KPIs. On this direction, a team leader was defined for each team and the communication regarding the progress on the given work was conducted absolutely with the leader of each team.

Step 2

The **second step** involves the definition of the most appropriate KPIs, which will allow a quantitative assessment of the performance of the upgraded technologies. The KPIs were designed to capture the key differences between the baseline and the upgraded scenarios, with a focus on aspects such as overall system performance, energy consumption, Global Warming Potential (GWP) production capacity, etc.

For this purpose, KPI Cards Templates were developed by CERTH and shared with the working teams, allowing for a more compact and structured representation of each KPI, which ensures consistency throughout the evaluation process. Each KPI Card includes detailed information such as the KPI's name, description, symbol, units, and formula, along with the identification of the parameters to be measured, calculated, or estimated. Furthermore, it specifies the partner responsible for data collection and KPI calculation, as well as the relevance of the KPI to the baseline scenario, the upgraded scenario, or the comparison between them. It is important to state that each KPI received a unique code related to its KPI category. For example, the first environmental KPI got the code "ENV-KPI-01".

Step 3

The **third step** focuses on the identification of key process-driven parameters, which are directly related to the defined KPIs. Representative parameters, such as temperature and pressure levels, energy consumption, system durability, and production capacity, serve as the critical variables for performance monitoring and therefore corresponding KPIs calculation. To ensure a comprehensive gathering of the key process-driven parameters, two parameters list templates (one initial and one final) were developed by CERTH. The initial template was first shared to the four working teams in order to gather all the parameters to be measured for each KPI category separately, while the final template was completed by CERTH through the combination of all the initial parameters' lists.

Step 4

Finally, the **fourth step** dedicates to the definition of the necessary sensor specifications and quantities, required to measure the key process-driven parameters in real-time. This includes the selection of appropriate sensor types with the required technical specifications, as well as the definition of the measurement strategy for each demonstration activity. For avoiding confusion, a final list of equipment was created by CERTH in order to concentrate all the measuring equipment which is needed for monitoring all the defined key process-driven parameters, by indicating the availability of the equipment, the proposed models including their technical specifications, the required quantity, potential suppliers as well as the parameters to be measured with each instrumentation. This list was completed twice; once for DEMO I and once for DEMO II. Following this, another detailed list including all the main

technical specifications and giving access to the datasheets of the proposed equipment via links was established for both DEMOs.

Step 5

As a final step (**step 5**) it was essential to clarify and clearly determine the responsible partners as far as the measuring equipment procurement and the monitoring process are concerned. Thus, a severe discussion among the partners took place in order to share properly the responsibilities regarding these two critical issues and to define the exact contribution of each partner in the treatment (instrumentation procurement and monitoring) of the key process-driven parameters of each KPI in both DEMOs.

By following this structured approach, the deliverable aims to establish a solid foundation for the evaluation of the upgraded induction and microwave heating technologies, while ensuring accurate data collection and reliable KPI calculation. The results of this work will allow the project to demonstrate the potential of these two innovative technologies to improve energy efficiency, reduce CO_2 emissions, and enhance production performance, while supporting their scalability and a wider adoption in energy-intensive industries.

1.1 Contribution from partners

The contribution of each partner in the definition of KPIs was organized based on their expertise and the focus of each KPI category. For **technical KPIs**, **CIRCE**, **ART**, and **SIML** were responsible for defining KPIs specifically related to the evaluation of the **induction heating system** in the **rubber vulcanization process** that take place in ARTIGO S.A. industry. Similarly, **KTH**, **K-FLEX**, and **CEI** focused on the development of KPIs for assessing the performance of the **microwave heating system** in the **multilayer pipe gluing process** that take place in K-FLEX S.A. industry. Additionally, these partners collaborated on defining KPIs that will evaluate the performance of **both heating systems** in comparison.

For **environmental KPIs**, **CERTH** takes the lead in defining indicators for both systems, ensuring that each KPI effectively assesses the **environmental impact** of both induction and microwave heating technologies.

When it comes to **economic KPIs**, **CERTH** and **CORE** mainly worked together to define the relevant indicators for **both systems**, focusing on economic performance aspects such as cost efficiency, energy savings, and overall financial viability.

Lastly, **social KPIs** were defined by the cooperation of **ISQ** and **STAM**, who focused on evaluating the **social impact** of both heating technologies, considering factors such as worker health and safety issues, social acceptance and job creation. Each KPI is crafted with the goal of assessing both the **induction and microwave heating systems**, ensuring a comprehensive evaluation across all dimensions.

The contribution of each partner to the KPIs definition is clearly described in Table 2: Contribution table.

Number	Partner	Contribution	Responsibility rate
1	CERTH	T4.2 leader. Deliverable writing Environmental KPIs definition for both heating systems Economic KPIs definition for both heating systems Measuring equipment determination	Main responsible
2	CIRCE	Technical KPIs definition for induction heating system	Main responsible
3	ART	Technical KPIs definition for induction heating system Measuring equipment determination	Supporter
4	SIML	Technical KPIs definition for induction heating system	Supporter
5	K-FLEX	Technical KPIs definition for microwave heating system Measuring equipment determination	Main responsible
6	KTH	Technical KPIs definition for microwave heating system	Supporter
7	CEI	Technical KPIs definition for microwave heating system	Supporter
8	CORE	Economic KPIs definition for both heating systems	Supporter
9	EDP	Economic KPIs definition for both heating systems	Supporter
10	UNIGE	Economic KPIs definition for both heating systems	Supporter
11	ISQ	Social KPIs definition for both heating systems Measuring equipment determination	Main responsible
12	STAM	Social KPIs definition for both heating systems	Supporter

Table 2: Contribution table

1.2 Relation to other project activity table

Task	Relation to other project activities
T4.1 - Analysis of use cases and definition of main system requirements, functionalities and flexibility	Theorical modelling of the solution
T7.3 & T8.3 - Expansion of LCA assessment tool	APIs development need sensors' specifications which are defined in this deliverable
T11.4 - Life cycle assessment of JOULIA solutions	Calculation of environmental and economic KPIs which are defined in this deliverable

Table 3: Relation to other project activities

2. KPIs definition

2.1 KPIs definition methodology

In this section, the main Key Performance Indicators (KPIs) for JOULIA project solutions are established and presented in detail. These KPIs will be utilized in assessing the technical, environmental, economic and social impact of the two new integrated electrified systems (induction and microwave heating system) which will be integrated into the industrial processes of rubber vulcanization and multilayer pipe gluing of ARTIGO and K-FLEX industries respectively. Four main steps were followed for the definition of suitable KPIs in each category.

At first, the task consortium was divided into four different working groups, each one dedicated to each KPIs' category. The first team, which was composed by CIRCE, ART, SIML, KTH, K-FLEX, and CEI, was responsible for the establishment of technical KPIs (T-KPIs). The second group consisted of CERTH and ART was dedicated to the environmental KPIs (ENV-KPIs) definition. As regards the third working team, partners CERTH and CORE had cooperated with each other and held the responsibility of economic KPIs (EC-KPIs) establishment, while the last group focused on the social KPIs, with ISQ and STAM being part of this. A team leader was set in each team group to be responsible for coordinating activities, distributing work, and ensuring the timely delivery of work outputs.

As a second step several indicated KPIs for each KPIs' category were proposed and distributed to the four working groups as guidance for the detailed establishment of suitable KPIs in each case. The indicated Technical KPIs considered aspects such as energy consumption, efficiency, scalability and ramp-up/down rates of the system. Indicated Environmental KPIs focused on metrics like Greenhouse Gasses (GHG) emissions, carbon payback time and primary energy consumption. Indicated Economic KPIs targeted on operational cost savings, payback periods, and investment costs per unit of product, while indicated social KPIs had to do with improvements in worker safety, training efforts, and stakeholder acceptance.

To facilitate a coherent KPI development, a common KPI card template was created by CERTH and shared among all partners. Each KPI card included fields for the KPI's name, code (e.g. ENV-KPI-01), category (e.g. environmental), description, symbol, units, the calculation formula or method and data sources with assumptions where necessary. Fields for KPI parameter categorization and calculation responsibility were also included in this KPI card template. This uniform format was proposed to be adopted to ensure clarity, comparability, and transparency across the KPIs definition activities, while it is crucial for the definition of the key process-driven parameters in Section 3. The KPI card template is given in Table 4 next, including the guidelines information in each cell.

KPI's CARD / *KPI's CODE*								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**		**Economical**		**Social**	
KPI's Code	*Syntax: X-KPI-Y* *X: "T-" for technical, "ENV-" for environmental, "EC-" for economical and "S-" for social KPIs.* *Y: Number of the KPI (e.g. 1, 2, 3… etc.)* *Example: ENV-KPI-1 (first environmental KPI)*							
KPI's Name	*Name of the KPI (8 words maximum)*							
KPI's Description	*Describe the meaning of the KPI and what it measures (50 words maximum)*							
KPI's Symbol	*Symbol of the KPI (e.g. O_{GHG}^{X})*							
KPI's Units	*Units of the KPI (e.g. tCO_2-eq/year)*							
KPI's Determination Type	**Calculation**	*Set "X" if the KPI is calculated through a formula*		**Measurement**	*Set "X" if the KPI is directly measured*			
KPI's Formula	*Provide the KPI's mathematical equation (if any)*							
KPI's formula's parameters' explanation	*Explain all the parameters involved in the KPI's formula, including subscripts and superscripts.*							
KPI's parameters to be measured	*Provide the parameters of the KPI's formula which should be measured*							
KPI's parameters to be calculated	*Provide the parameters of the KPI's formula which should be calculated*							
KPI's parameters to be found or estimated	*Provide the parameters of the KPI's formula which should be found/estimated (e.g. Primary Energy Factor, Emissions Factor etc.)*							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**	*Set "X" if the KPI will be used for IS-1 evaluation*	**IS-2**	*Set "X" if the KPI will be used for IS-2 evaluation*	**All**	*Set "X" if the KPI will be used for IS-1 & IS-2 evaluation*		
KPI's correspondence (Case under evaluation)	**Baseline Scenario (BS)**	*Set "X" if the KPI will be used for BS evaluation*	**Upgraded Scenario (US)**	*Set "X" if the KPI will be used for US evaluation*	**All**	*Set "X" if the KPI will be used for BS and US evaluation*		
KPI's Calculation Responsible	*Provide the partner which is responsible for the calculation of the KPI (e.g. CERTH)*							

Table 4: KPI's card template

Additionally, great emphasis was given in the fact that each KPI should include a detailed description of what it measures/evaluates and a clear calculation method or formula, with a comprehensive explanation of all the parameters involved, while it was, also, important to determine which of these parameters need to be measured, calculated or estimated. This was followed to guarantee that the KPIs will be accurately defined and the calculation of each KPI will be pre-defined and well-organized, while it was critically significant regarding the key process-driven parameters definition and the determination of the measurement instrumentation needed for these parameters' monitoring. This information was important and thus it was requested on the KPIs' cards. As a next step, comprehensive and detailed guidelines were provided to the working groups to assist them in defining the KPIs and completing/filling properly the KPIs' cards. More specifically, each working team was instructed to identify relative KPIs used in other similar cases in literature, to get an idea regarding the evaluation of indicators which are commonly used on such applications. Another important thing that partners should attend was that the KPIs should be defined in a way that they are suitable for the evaluation of both demonstrators and focused on the comparison between the baseline and the upgraded set-up in each demo case. In particular, the majority of the KPIs had to be selected carefully to fit properly in both demos and to reflect the main differences between the baseline and the upgraded scenarios in each demo site ensuring that

the selected indicators were impactful and aligned with the project objectives. As a final guideline, a maximum limitation on the number of KPIs per category was set in order to maintain focus and manageability.

2.1 Technical, Environmental, Economic and Social KPIs definition

2.1.1 Technical KPIs

In JOULIA project, several Technical Key Performance Indicators (T-KPIs) have been established for evaluating the technical characteristics of the new integrated systems (induction and microwave heating systems) in comparison to the baseline system in ART and K-FLEX facilities. Great emphasis is given on the assessment of the thermal performance, the electrical energy consumption, the thermal energy input and the effectiveness of each system while indicators regarding the examined production line process were, also, implemented for the evaluation of the final product quality in terms of temperature and magnetic fields uniformity as well as stability of the process. The defined KPIs focus on the main differences between the baseline and the upgraded case in each demonstrator with mutual KPIs to be defined for both demo cases. After a thorough investigation and a detailed analysis, the first working team led by CIRCE came up with seven technical KPIs. The finalization of these KPIs was conducted by CERTH with various changes to take place regarding the definition of each KPI and the parameters involved in the calculations. The technical KPIs defined for the needs of JOULIA assessments are the following:

- **T-KPI-01: Temperature to Energy Ratio (°C/kWh)**: Measures the efficiency of energy input by evaluating the achieved process temperature per unit of input energy, providing insight into the heating system's effectiveness in reaching the required temperature levels.
- **T-KPI-02: Energy Consumption per Mass Produced (kWh/kg)**: Quantifies the amount of thermal or electrical energy consumed per unit mass of material processed, offering a normalized metric to compare energy efficiency across heating systems for equivalent material quantities.
- **T-KPI-03: Temperature Uniformity Index (%)**: Assesses the uniformity of temperature distribution during the heating process by quantifying the difference between the maximum and the minimum temperatures relatively to the average temperature across the heated zone; a lower index indicates a more uniform temperature distribution and enhanced consistent material properties.
- **T-KPI-04: Magnetic Field Distribution Uniformity (%)**: Evaluates the uniformity of the magnetic field within the heating zone considering that a more uniform field (low indicator values) leads to a consistent heating which is critical for proper rubber vulcanization.
- **T-KPI-05: Antenna/Cavity Tuning Accuracy and Responsiveness (Hz)**: Measures the precision and responsiveness of microwave antenna/cavity tuning. This is a crucial indicator since it is important to achieve optimal magnetic field distribution within the heating area for ensuring consistent heating during the pipe multilayer gluing processes. It is obvious that higher accuracy and responsiveness indicate enhanced performance.
- **T-KPI-06: Process Temperature Repeatability/Stability (°C)**: Quantifies the system's ability to maintain consistent temperature over time under continuous operation; a lower coefficient of variation reflects better process stability and more reliable performance.

These KPIs are designed to monitor and evaluate the technical performance of the induction and the microwave heating systems by comparing them with the respective baseline heating set-ups, in order to report the improvements coming with the implementation of the new systems in performance, in energy consumption and in other technical characteristics as regards the process itself and the final product.

2.1.2 Environmental KPIs

Within the framework of the JOULIA project, Environmental Key Performance Indicators (ENV-KPIs) have been defined to assess the environmental benefits, arising from the technological upgrades implemented in the two industrial demonstrators of ARTIGO and K-FLEX. The definition of the ENV-KPIs was conducted by considering the major differences between the baseline and the upgraded system in each demo case while great emphasis was given in considering common ENV-KPIs for both implemented technologies (induction, microwave). Thus, eight ENV-KPIs have been established to assess the environmental impact of the new technologies in depth. The environmental impact of both integrated technologies is evaluated through the following KPIs:

- **ENV-KPI-01: Operational GHG Emissions (Annual) ($t_{CO2\text{-}eq}$/year)**: It quantifies the total GHG emissions associated with the standard operation of each process.
- **ENV-KPI-02: Operational GHG Emissions Reduction (Annual) (%):** It measures the yearly decrease in GHG emissions achieved with the valorization of the upgraded technologies compared to the baseline set-up in each demo case.
- **ENV-KPI-03: Operational Primary Energy Consumption (Annual) (MWh_{PE}/year):** It calculates the annual amount of energy required for each process in terms of primary energy.
- **ENV-KPI-04: Operational Primary Energy Consumption Reduction (Annual) (%):** It reflects the savings in primary energy ensured with the upgrade in each case.
- **ENV-KPI-05: Fossil Fuel Reduction (Annual) (%):** It assesses the yearly decrease in the use of fossil fuel due to the adoption of the induction and the microwave heating technologies.
- **ENV-KPI-06: Lifetime GHG Emissions ($t_{CO2\text{-}eq}$):** It estimates the total GHG emissions over the expected lifetime of each integrated system.
- **ENV-KPI-07: Lifetime Primary Energy Consumption (MWh_{PE}):** It expresses the overall primary energy consumption throughout the system's lifetime in each demo case.
- **ENV-KPI-08: GHG Emissions Payback Period (years)** defines the time required for the emissions savings generated by the upgrades to offset the emissions embedded in the production and deployment of the new technologies.

Through the monitoring and evaluation of these KPIs, the project aims to demonstrate substantial environmental benefits coming from the implemented novel technologies, supporting the transition to cleaner, more energy-efficient and decarbonized industrial processes.

2.1.3 Economic KPIs

The assessment of JOULIA interventions is not limited only to the technical and the environmental impact but, also, the economic evaluation is set under the scope of the project. For this reason, seven different economic KPIs were determined focusing on investment viability, the capital costs and the payback time for each of the two new integrated systems. The main responsible partner for the development and the calculation of the economic KPIs is CERTH with the gentle contribution of CORE. The finalization of the KPIs was conducted by CERTH. The JOULIA economic KPIs are the following:

- **EC-KPI-01: Capital Expenditure (CAPEX) (€)**: Quantifies the total investment required for the new integrated system, encompassing equipment costs, installation expenses, and infrastructure upgrades.
- **EC-KPI-02: Relative CAPEX (€/kW)**: Represents the CAPEX of the new integrated system normalized by the total installed power of the new system, facilitating comparative analysis of investment efficiency.
- **EC-KPI-03: Operational Expenditure (OPEX) (Annual) (€/year)**: Measures the annual expenses associated with the system's operation, including expenses such as maintenance, energy, and labor costs.
- **EC-KPI-04: Relative OPEX (Annual) (€/t)**: Calculates the annual OPEX per unit of produced product, providing insights regarding operational cost effectiveness relatively to the production output.
- **EC-KPI-05: Profit Margin (%)**: Indicates the percentage of revenue remaining as profit after all expenses are compensated, reflecting the system's profitability and cost management effectiveness.
- **EC-KPI-06: Net Present Value (NPV) (%)**: Determines the profitability of the investment by calculating the difference between the present value of cash inflows and outflows over a specified period, considering a particular discount rate.
- **EC-KPI-07: Payback Period (years)**: Indicates the number of years required for the costs savings achieved generated by the upgrades to equal the costs incurred from the installation and operation of the system.

These KPIs are designed to monitor and evaluate the economic characteristics of the new integrated systems in the two industrial sites, ensuring an in-depth evaluation of the investment profitability, the capital costs, the operational expenditure and the compensation period in each case.

2.1.4 Social KPIs

Apart from the technical, environmental and economic evaluation of the JOULIA innovative integrated systems, social impact assessments will also take place with the definition of five specific social KPIs. These KPIs have mainly to do with safety and comfort issues as regards the working environment and the effects of the new integrated system in the employees' health, focusing on the workplace temperature monitoring, assessing the exposure to electromagnetic fields and recordability of health disorders and accidents mainly related to the integrated systems. It is important to mention that the social impact assessment will be conducted in comparison to the baseline set-up in each examined case in order to conduct a reliable evaluation of the new heating technologies. The social KPIs were defined properly in accordance with the scope of the project by ISQ and STAM, while CERTH contributed to the finalization of them. The following KPIs were established for the evaluation of the social impact of the JOULIA heating technologies:

- **S-KPI-01: Total Electrical Recordable Incident Rate (%)**: Measures the incidence rate of electrical recordable injuries and illnesses associated with the operation of microwave and induction heating systems. This KPI reflects the effectiveness of safety protocols in mitigating electrical accidents in the workplace.
- **S-KPI-02: Workplace Temperature Monitoring (%)**: Assesses the compliance with the predetermined comfort temperature range (e.g., 20–24 °C) mostly in areas near the microwave and the induction heating devices. Monitoring methods include automated temperature logging

systems, manual readings, and employee feedback through regular surveys. Maintaining temperatures within the comfort range is a crucial precondition for ensuring a comfortable working environment and for enhancing productivity.

- **S-KPI-03: Normalized EMF Exposure Level – Induction Heating (%)**: Evaluates the ratio between the measured magnetic flux density at areas near the induction heating system and the corresponding Exposure Limit Values (ELVs) for thermal effects, as defined in Directive 2013/35/EU. This KPI ensures that the workers are exposed to electromagnetic fields within the safe limits.
- **S-KPI-04: Normalized EMF Exposure Level – Microwave Heating (%)**: Assesses the ratio between measured electric field strength, magnetic field strength, power density, and (optionally) estimated specific energy absorption rate at areas near the microwave heating system, relatively to the ELVs for thermal effects outlined in Directive 2013/35/EU. This KPI monitors compliance with occupational electromagnetic fields' exposure standards.
- **S-KPI-05: Occupational Noise Level Compliance (ONLC) (%)**: Determines whether the daily noise levels and the peak sound pressure on which the workers are exposed comply or not with the safety limits established by Directive 2003/10/EC. This KPI is evaluated for each worker to ensure adherence to occupational noise regulations.

These KPIs are designed to monitor and evaluate the social aspects of workplace health, safety and comfort in working environments that utilize the electrified heating technologies of the present project, ensuring compliance with relevant European directives and promoting a safe and comfortable working environment.

3. Key - process driven parameters definition

3.1 Key - process driven parameters definition methodology

In the framework of JOULIA project, the definition and the monitoring of the key process-driven parameters play a significant role in the calculation and the comprehensive evaluation of the already defined Technical, Environmental, Economic and Social Key Performance Indicators (KPIs). Hence, it is more than crucial to define properly the main parameters which need to be measured and monitored in each of the two industrial processes (DEMO I: induction heating in rubber vulcanization, DEMO II: microwave heating in multilayer pipe gluing) in ART and K-FLEX industries respectively. This subtask needed the effort of all the partners involved in T4.2 with great emphasis on the contribution of CERTH and on the two demonstrators' partners; ART and K-FLEX. The parameters had to be defined separately for each demonstrator considering that there are plenty differences between the two DEMOs, while there are some specific KPIs dedicated to each demonstrator, which were not defined for the evaluation of both DEMOs.

The first step for the definition of the key process-driven parameters has already been taken from the initial definition of each KPI. More specifically, these parameters are the ones reported in each KPI card in the "KPI's parameters to be measured" field something that it has already been done in Section 2. Following this step, a comprehensive template for gathering the key process-driven parameters was developed for each KPI category. This template categorizes each parameter by its relevance to one or more KPIs considering all KPIs categories, the feasibility of its measurement, the proposed measurement instrumentation type, indicated models of the measuring equipment and suggested alternatives in cases where direct measurement is not feasible. This was an initial action for gathering the key process-driven parameters in each case. The main structure of the prementioned initial template is given in Table 5 including the instructions for the partners.

As a third step, a detailed procedure was followed by CERTH focusing on the identification of common parameters in the several different KPIs' cards, for finalizing the parameters to be measured and avoid double references to any variable involved. Part of this procedure was the development of a final parameters list template by CERTH, in an attempt to concentrate all the key process-driven parameters of all the KPIs in one concentrated list. Considering that during the phase of filling out the initial lists there was not any significant measurement feasibility issue mentioned in them. The final template was structured as the initial one, by excluding the "Alternative monitoring" column. The structure of the final concentrated parameters' list template is available in Table 6. It has to be clarified that this template was filled twice, each time for each one of the demonstrator sites (ART and K-FLEX) since not all the KPIs were defined for the evaluation of both DEMOs as was mentioned earlier in the present report. Hence, there were two final concentrated parameters' lists created from this final parameters' list template.

In both DEMOs, the key process-driven parameters focus on the technical, the environmental, the economic and the social assessment of the proposed solution and the baseline system in each case. These parameters are utilized either directly via measurements or indirectly by being involved in secondary calculations and they are related mainly to the overall performance monitoring, GHG emissions, product quality, annual production capacity, power consumption and safety protocols.

All the prementioned key process-driven parameters are of great importance since apart from the consistent monitoring they ensure, especially regarding the new integrated systems, they also provide the essential input required for the calculation of the majority of the already defined KPIs.

PARAMETERS TO BE MEASURED AND MEASUREMENT EQUIPMENT						
KPIs' Category	*Indicate the category of your KPIs (e.g. Technical)*					
DEMO	*Indicate the DEMO (e.g. DEMO I)*	**Industry**	*Indicate the industry of the DEMO (e.g. ART)*			
No.	**Parameter**	**Involved KPI/KPIs**	**Measurement feasibility**	**Measuring Equipment Type**	**Measuring Equipment Model/other information**	**Alternative monitoring**
1	*Indicate the parameters to be measured for each KPI (use both the symbol and the short description of each parameter)*	*Indicate the KPI/KPIs which utilize this parameter (e.g. T-KPI-01 etc.)*	*Indicate YES in case it is feasible to measure the parameter or NO in case it is not feasible*	*Propose indicative measuring equipment type for measuring the parameter (e.g. temperature sensor etc.)*	*Please provide models of the proposed instrumentation (e.g. PT100 etc.)*	*Propose alternative ways for taking values in case measurement is not feasible (e.g. indirectly through other parameters, from simulation results etc.)*
2						
…						

Table 5: Initial parameters' list template

PARAMETERS TO BE MEASURED AND MEASUREMENT EQUIPMENT					
KPIs' Category	All categories				
DEMO	*Indicate the DEMO (e.g. DEMO I)*	**Industry**	*Indicate the industry of the DEMO (e.g. ART)*		
No.	**Parameter**	**Involved KPI/KPIs**	**Measurement feasibility**	**Measuring Equipment Type**	**Measuring Equipment Model/other information**
1					
2					
…					

Table 6: Final concentrated parameters' list template

3.2 Key process-driven parameters list for all KPIs categories - DEMO I

In **DEMO I**, led by ART, the first key process-driven parameters are the **mass flow rate** ($\dot{m}_{th.oil}$) as well as the **inlet and outlet temperatures** ($T_{in,th.oil}$ and $T_{out,th.oil}$) of the thermal oil, the **electrical power consumption** (P_X) and the **photovoltaic electrical power input** contributing to the process ($P_{PV,X}$). These parameters are involved in several environmental, economic and technical KPIs of the present project. Several product-related parameters were also peaked out from the KPIs' calculation parameters contributing to calculating technical KPIs related to process efficiency and product output quality. These parameters are the **thickness** (TH) and the **width** (W) of the final product, the **production line velocity** (u), the achieved **process temperature** ($T_{process}$), as well as the **maximum and minimum heating zone temperatures** (T_{max}, T_{min}). The **annual production quantity** (APQ) was also considered as a key parameter in an economic KPI calculation. Several parameters were also defined considering the social perspective on the evaluation of the induction heating system compared to the baseline one in DEMO I. In particular, the **number of the temperature checks** (TC) that record temperatures within the range of the temperature comfort range will be documented. These checks will be conducted at strategic locations near the heating system and the workplace generally. Measurement frequency depends on the type of work environment and subsequent risk levels. Nevertheless, consistent monitoring of workplace temperatures is crucial for ensuring worker comfort and productivity. Thus, ideally, temperature can be monitored continuously with alarms, setting the limits of comfort temperature. In case it is not possible to implement the continuous monitoring, the measurements could be taken 2 times per shift, when processes or equipment change during the shift, when weather conditions change significantly or when employees complain about discomfort. Carrying out thermal comfort surveys could be also a useful resource to provide indication for monitoring and risk assessment. Additionally, the exposure to the **magnetic flux** of the induction device ($B_{measured}$), the **noise levels during an 8-hour shift** ($L_{EX,8h}^{Measured}$), and the **peak sound pressure** ($p_{peak}^{Measured}$) inside the workplace near the examined process will be recorded for the evaluation of the safety and comfort of the working environment. It is significant to state that in the key process-driven parameters analysis framework, the main proposed instrumentation accompanied by their main specifications are defined separately for each one of the determined parameters. The concentrated parameters list that includes all the key process-driven parameters to be measured with their measuring equipment from all the KPIs' categories regarding DEMO I in ARTIGO industry are included in

No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
13	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers	**S-KPI-02**	YES	Examples: Thermometer, hygrometer, anemometer, wet bulb globe temperature (WBGT) Monitors	VelociCalc Air Velocity Meter TSI 9545-A TSI Alnor TH-Calc 7415 or 7425 (Compliant with ISO 7243 and ACGIH WBGT guidelines.)

	stations; Storage areas having temperature-sensitive materials.				
14	$B_{measured}$: Magnetic flux density in µT (measured)	**S-KPI-03**	YES	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30 (Hall effect sensor or fluxgate probe)
15	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	DEM201
16	$p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	DEM201

Table 7.

PARAMETERS TO BE MEASURED AND MEASUREMENT EQUIPMENT					
KPIs' Category	All categories				
DEMO	DEMO I	Industry	ART		
No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
1	$\dot{m}_{th.oil}$: Mass flow rate of thermal oil (kg/s)	**ENV-KPI-01** **EC-KPI-03** **T-KPI-01** **T-KPI-02**	YES	Flow meter	FLEXIM FLUXUS G601 CA ENERGY
2	$T_{in,th.oil}$: Thermal oil inlet temperature (°C)	**ENV-KPI-01** **EC-KPI-03** **T-KPI-01** **T-KPI-02**	YES	Temperature sensor	TS EKat PT100

No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
3	$T_{out,th.oil}$: Thermal oil outlet temperature (°C)	**ENV-KPI-01 EC-KPI-03 T-KPI-01 T-KPI-02**	YES	Temperature sensor	TS EKat PT100
4	P_X: electrical power consumption in the process (MW)	**ENV-KPI-01 EC-KPI-03 T-KPI-01 T-KPI-02**	YES	Electrical power consumption meter	EMA CONTREL 90N
5	$P_{PV,X}$: PV electrical power in the process (MW)	**ENV-KPI-01 EC-KPI-03**	YES	Electrical power consumption meter	EMA CONTREL 90N
6	**TH:** Thickness of the floor produced (m)	**T-KPI-02**	YES	Tape measure	-
7	**W:** Width of the floor produced (m)	**T-KPI-02**	YES	Tape measure	-
8	**u:** Velocity of the floor (m/s)	**T-KPI-02**	YES	Parameter from the Variable Speed Drive system	-
9	$T_{process}$: Temperature achieved in the process (°C)	**T-KPI-01**	YES	Thermocamera	FLIR Thermocamera E86
				Infrared thermometer	OPTRIS CT 3ML infrared thermometer
				Temperature sensors	Roller temperature probes for curved surfaces
10	T_{max}: Maximum temperature across the heated zone (ºC)	**T-KPI-03**	YES	Thermocamera	FLIR Thermocamera E86
				Infrared thermometer	OPTRIS CT 3ML infrared thermometer
				Temperature sensors	Roller temperature probes for curved surfaces
11	T_{min}: Minimum temperature across the heated zone (ºC)	**T-KPI-03**	YES	Thermocamera	FLIR Thermocamera E86
				Infrared thermometer	OPTRIS CT 3ML infrared thermometer
				Temperature sensors	Roller temperature probes for curved surfaces
12	**APQ:** Annual produced quantity of the product (e.g. t/year or m/year)	**EC-KPI 04**	YES	This parameter is measured through monthly reporting	Available monthly production reports for: • Gross flooring (kg or m^2). • Net flooring (kg or m^2). • Flooring to the warehouse (kg or m^2). These data are available at global or at single line level. ISO 50001 certified data.

No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
13	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.	**S-KPI-02**	YES	Examples: Thermometer, hygrometer, anemometer, wet bulb globe temperature (WBGT) Monitors	VelociCalc Air Velocity Meter TSI 9545-A TSI Alnor TH-Calc 7415 or 7425 (Compliant with ISO 7243 and ACGIH WBGT guidelines.)
14	$B_{measured}$: Magnetic flux density in μT (measured)	**S-KPI-03**	YES	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30 (Hall effect sensor or fluxgate probe)
15	$\boldsymbol{L_{EX,8h}}^{\boldsymbol{Measured}}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	DEM201
16	${p_{peak}}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	DEM201

Table 7: Final concentrated parameters' list for DEMO I

3.3 Key process-driven parameters list for all KPIs categories - DEMO II

In **DEMO II**, coordinated by K-FLEX, the key process-driven parameters include the **electrical power consumption** (P_X), the **outer and inner pipe diameters** (D_o, D_i), the **production line velocity** (u), and the full temperature profile of the process ($T_{process}$, T_{max}, T_{min}) as in DEMO I. The **actual operational frequency** (f_{actual}) of the microwave system is another key parameter to be monitored, as it directly influences the efficiency of the system and the energy distribution on the process. The **annual production quantity** (APQ) is also taken into consideration as in DEMO I, since it is a reliable metric for comparing the upgraded system to the respective baseline. DEMO II, also, includes **temperature checks** (TC) in critical zones and a series of electromagnetic field measurements: **incident electric field strength** ($E_{inc\text{-}Field\_measured}$), **magnetic field strength** ($H_{inc\text{-}Field\_measured}$), and **power density** ($S_{inc\_measured}$), to address workplace safety issues. The **noise levels** and the **peak sound pressure** are taken into account as in DEMO I case for the calculation of specific social KPIs. It is important here to mention that the main measuring equipment for the defined parameters are also determined as in DEMO I. The concentrated parameters' list that includes all the key process-driven parameters to be measured with their measuring equipment from all the KPIs' categories regarding DEMO II in K-FLEX industry are included in Table 8.

PARAMETERS TO BE MEASURED AND MEASUREMENT EQUIPMENT					
KPIs' Category	All categories				
DEMO	DEMO II	**Industry**	K-FLEX		
No.	**Parameter**	**Involved KPI/KPIs**	**Measurement feasibility**	**Measuring Equipment Type**	**Measuring Equipment Model/other information**
1	**P_X:** electrical power consumption in the process (MW)	**ENV-KPI-01 EC-KPI-03 T-KPI-01 T-KPI-02**	YES	Electrical power consumption meter	LUMEL NR32 Sonel mpi 540
2	**D_o:** Outer diameter of the pipe (m)	**T-KPI-02**	YES	Laser Metter measure	SIKORA LASER 2100
3	**D_i:** Inner diameter of the pipe (m)	**T-KPI-02**	YES	Microscope	Keyence microscope
4	***F*pull:** Adhesion of the different layers using a pulling rig	**T-KPI-02**	YES	Dynamometer	Zwick roller
5	**R:** thermal durability of the outer layer of pipe on the basis of resistance to cracking after aging in a dryer	**T-KPI-02**	YES	Dynamometer	Zwick roller
6	**u:** Velocity of the pipe (m/s)	**T-KPI-02**	YES	Parameter from the Variable Speed Drive system	Online measurement equipment

No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
7	$\mathbf{T_{process}}$: Temperature achieved in the process (°C)	**T-KPI-01**	YES	Thermocamera	FLIR Thermocamera E86
8	$\mathbf{T_{max}}$: Maximum temperature across the heated zone (ºC)	**T-KPI-03**	YES	Thermocamera	FLIR Thermocamera E86
9	$\mathbf{T_{min}}$: Minimum temperature across the heated zone (ºC)	**T-KPI-03**	YES	Thermocamera	FLIR Thermocamera E86
10	$\mathbf{f_{actual}}$:Actual frequency of operation (Hz)	**T-KPI-05**	NO	-	-
11	**APQ:** Annual produced quantity of the product (t/year)	**EC-KPI 04**	YES	This parameter is measured through monthly reporting	Monthly production report
12	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.	**S-KPI-02**	YES	Examples: Thermometer, hygrometer, anemometer, wet bulb globe temperature (WBGT) Monitors	VelociCalc Air Velocity Meter TSI 9545-A TSI Alnor TH-Calc 7415 or 7425 (Compliant with ISO 7243 and ACGIH WBGT guidelines.)
13	$\boldsymbol{E_{inc} - Field_{measured}}$ – incident electric field strength (volt per meter $V.m^{-1}$)	**S-KPI-04**	YES	Electromagnetic field meter	WAVECONTROL – SMP2 Measurement range in V/m - frequency range for induction and microwave systems (e.g., 50 Hz to 60 GHz for microwave)

No.	Parameter	Involved KPI/KPIs	Measurement feasibility	Measuring Equipment Type	Measuring Equipment Model/other information
14	$H_{inc} - Field_{measured}$ – incident magnetic field strength (ampere per meter A.m^{-1})	**S-KPI-04**	YES	Gaussmeter, Magnometer	Magnometer PCE-EMF 30 Suitable for low- and high-frequency measurements (from DC to high-frequency fields)
15	$S_{inc_{measured}}$ – incident power density (S_{inc}, watt per square meter, W.m^{-2})	**S-KPI-04**	YES	Power meter or EMF meter	WAVECONTROL – SMP2 Measure electromagnetic energy density per unit area in W/m²
16	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	SVAN 971
17	$p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.	**S-KPI-05**	YES	Sound level meter	SVAN 971

Table 8: Final concentrated parameters' list for DEMO II

4. Measuring equipment selection, specifications and quantity

After the definition of the technical, environmental, economic and social KPIs as well as the determination of the main key process-driven parameters arisen from each KPI within the framework of JOULIA project interventions assessment, the final list of equipment was essential to be created. This equipment list was established for each one of the DEMO cases separately. The main reason for creating such a list is to gather all the measurement instrumentation which needs to be utilized in each DEMO and to identify which equipment is already available and which needs to be ordered and purchased. For this reason, a comprehensive final equipment list was developed by CERTH with all the necessary information included. In particular, important information regarding the equipment type, the model, the required quantity, the availability of the equipment, the potential suppliers and the key process-driven parameters the equipment measures are included in the final list. The template for the specific list is given in

No.	Equipment type	Model	Quantity	Availability	Supplier	Parameters to measure
1	*Indicate the type of equipment (e.g. flow meter)*	*Indicate the model of the equipment (e.g. FLEXIM G601)*	*Indicate the quantity of the equipment*	*Indicate whether the equipment is available/ existing or not*	*Indicate the supplier of the equipment*	*Indicate the parameter/s to be measured with the specific equipment*
2						
3						
…						

.

Following the determination of the basic information regarding the proposed equipment (type, models, quantity, suppliers), it was crucial to determine the technical characteristics of each model in detail. Thus, a new table in which the main features of the models are mentioned was established by CERTH. This table includes all the main technical specifications for each model providing at the same time access to the technical datasheets of the models via hyperlink, for getting a detailed overview regarding the operating features and specialties of the required equipment. Table 10 gives the template of the main specifications list for the equipment.

FINAL LIST OF EQUIPMENT						
DEMO	*Indicate the DEMO (e.g. DEMO I)*	Industry	*Indicate the industry of the DEMO (e.g. ART)*			
No.	Equipment type	Model	Quantity	Availability	Supplier	Parameters to measure

1	*Indicate the type of equipment (e.g. flow meter)*	*Indicate the model of the equipment (e.g. FLEXIM G601)*	*Indicate the quantity of the equipment*	*Indicate whether the equipment is available/ existing or not*	*Indicate the supplier of the equipment*	*Indicate the parameter/s to be measured with the specific equipment*
2						
3						
…						

Table 9: Final equipment list template

EQUIPMENT MAIN SPECIFICATIONS LIST					
DEMO	*Indicate the DEMO (e.g. DEMO I)*	**Industry**	*Indicate the industry of the DEMO (e.g. ART)*		
No.	**Model**	**Main Features**	**Technical Datasheet**	**Supplier**	
1	*Indicate the model of the equipment (e.g. FLEXIM G601)*	*Indicate at least five main specification features of the model*	*Indicate a representative link regarding the technical datasheet*	*Indicate the supplier of the equipment*	
2					
3					
…					

Table 10: Equipment main specifications list template

4.1 Measuring equipment in DEMO I

Table 11 includes all the necessary information regarding the measuring equipment which is proposed to be used in the case of DEMO I in ARTIGO facilities, regarding the rubber vulcanization process. Great emphasis was given in mentioning the type of equipment, the exact models of the required equipment and the quantity needed. It is necessary here to mention that because there are plenty of similar parameters (e.g. temperatures), some of the proposed equipment will be utilized for measuring more than one parameter. The availability of each instrument is reported to be aware of any procurement needs. Additionally, all potential suppliers regarding the proposed equipment are mentioned to provide full information for the required models. The parameters that each of the equipment measures are also included in the table.

FINAL LIST OF EQUIPMENT						
DEMO	DEMO I	Industry	ART			
No.	**Equipment type**	**Model**	**Quantity**	**Availability**	**Supplier**	**Parameters to measure**
1	Flow meter (portable instrument)	FLEXIM FLUXUS G601 CA ENERGY	1	YES	ICM	$\dot{m}_{th.oil}$: Mass flow rate of thermal oil (kg/s)
2	Temperature sensor	TS EKat PT100	>8 per rotocure	YES	Tersid	$T_{in,th.oil}$: Thermal oil inlet temperature (°C) $T_{out,th.oil}$: Thermal oil outlet temperature (°C)
3	Electrical power consumption meter	EMA CONTREL 90N	2	NO	IDG / BIESSE	P_X: electrical power consumption in the process (MW) $P_{PV,X}$: PV electrical power in the process (MW)
4a	Thermocamera	FLIR Thermocamera E86	1	YES	GEASS	$T_{process}$: Temperature achieved in the process (°C) T_{max}: Maximum temperature across the heated zone (ºC) T_{max}: Maximum temperature across the heated zone (ºC)
4b	Infrared thermometer	OPTRIS CT 3ML infrared thermometer	TBD	NO	Luchsinger	
4c	Roller temperature sensor	TRS-3	TBD	YES	Tersid	
6a	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	NO	TSI	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
6b	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	NO	TSI	
7	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	NO	PCE instru-ments	$B_{measured}$: Magnetic flux density in μT (measured)
8	Sound level meter	DEM201	1	NO	Velleman	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.

Table 11: Final equipment list for DEMO I

After the determination of all the basic information regarding the equipment needed for monitoring the key process-driven parameters in DEMO I case, it was important to provide the main specification

characteristics of each model. For this reason, the template regarding the main equipment specifications provided in Table 10 was utilized. In particular, CERTH accessed all the datasheets given by the partners involved and picked out the main technical characteristics and specifications of each model. Table 12 gives the main specifications of the measuring equipment proposed in DEMO I case. It is important to mention that a representative link is provided for getting access to the detailed technical datasheet of each proposed model and to get more information than the indicated data given in the "Main features" column, if necessary.

MAIN SPECIFICATIONS OF EQUIPMENT			
DEMO	DEMO I	**Industry**	ART

No.	Model	Main Features	Technical Datasheet	Supplier
1	FLEXIM FLUXUS G601 CA ENERGY	Measurement Range: 0.01–25 m/s (flow velocity) Accuracy: ±1% of reading (±0.005 m/s) Outputs: pulse, 4–20 mA, RS-232 Operating temperature (fluid): -40°C to +130°C (STD) -30°C to +240°C (HT) Ambient Temperature: -10°C to +60°C Protection: IP65 according to EN60529; IP67 for the transport case	TDS [1]	ICM
2	TS EKat PT100	Sensor element: Platinum resistor PT100 Temperature measurement range: –30 °C to +150 °C Accuracy class: Class B (±0.3 °C at 0 °C) Probe sheath material: Stainless steel (also available in brass), per Engler's standard tube options Process connection & electrical interface: Configurable various fittings and connection heads, allowing for flexible field installation	TDS [2]	Tersid
3	EMA CONTREL 90N	Available modules: • 4 digital inputs and 2 digital outputs • 2 digital inputs and 6 digital outputs • 8 digital outputs • 2 or 4 analog outputs • 4 digital outputs and 2/4 analog outputs Communication Interfaces: • RS485 (Modbus RTU) • ETHERNET (Modbus TCP, SNMP) • PROFIBUS-DP • M-BUS • ETHERNET GATEWAY (Allows reading data from a group of EMAs connected via RS485 network through a single Ethernet port) Energy metering: Active, reactive, apparent, imported, and exported energy meters, pulse type Alarms and controls: Alarm management, Programmable I/O functions, Stored data with a sequential number, date, and time. Features: Fresnel diagram, Current and voltage harmonics Display: digital screen, 96x96 mm	TDS [2]	IDG / BIESSE

No.	Model	Main Features	Technical Datasheet	Supplier

4a	FLIR Thermocamera E86 – 42°	Infrared Resolution: 464 × 348 pixels Temperature Range: -20°C to +650°C (extendable to +1500°C) Thermal Sensitivity: ≤0.03°C at 30°C Spectral Range: 7.5–14 µm Image frequency: 30 Hz Display: 4" touchscreen LCD	TDS [4]	GEASS
4b	OPTRIS CT 3ML infrared thermometer	Ambient temperature range: -20°C to +85°C Measurement temperature range: +50°C to +400°C Temperature Resolution: 0.1 K Optical Resolution: 22:1 (3ML), 33:1 (3MH), 75:1 (3MH1-3MH3) Accuracy: ±0.3% of reading (±2.0°C) Exposure Time: 1 ms Emissivity and Transmissivity Adjustment: 0.1–1.1	TDS [5]	Luchsinger
4c	TRS-3	-	-	Tersid
5a	VelociCalc Air Velocity Meter TSI 9545-A	Velocity Range: 0–30 m/s Accuracy (Velocity): ±3% of reading (±0.015 m/s) Temperature Range: -10°C to +60°C Accuracy (Temperature): ±0.3°C Relative Humidity Range: 5 to 95% RH Accuracy (Relative Humidity): 0.1% RH Outputs: USB, Bluetooth	TDS [6]	TSI
5b	TSI Alnor TH-Calc 7415 or 7425	Temperature Range: -10°C to +60°C Accuracy (Temperature): ±0.6°C Relative Humidity Range: 5 to 95% RH Accuracy (Relative Humidity): ±3% RH Data Logging: SD card storage Logging Interval: 1 sec to 3600 sec	TDS [7]	TSI
6	Magnometer PCE-EMF 30	Magnetic Field Range: 0.01–99.99 µT (DC/AC) Frequency Range: 5 Hz–100 kHz Resolution: 0.01 µT Accuracy: ±2% ±5 digits Power Supply & Battery Life: Rechargeable battery 3.7 V / 1,000 mAh, with auto power-off after 15 minutes of inactivity Protection: IP20	TDS [8]	PCE instruments
7	DEM201	Measurement Range: 30–130 dB Frequency Range: 31.5 Hz–8 kHz Accuracy: ±1.4 dB Weighting Curves: A/C Display: LCD with backlight	TDS [9]	Velleman

Table 12: Equipment main specifications for DEMO I

4.2 Measuring equipment in DEMO II

Table 13Table 11: Final equipment list for DEMO I provides all relevant details about the proposed measuring equipment for the multilayer pipe gluing process in K-FLEX industry (DEMO II). It specifies the parameters each instrument will measure, the type of equipment, the exact models and the required quantities along with their availability status to identify any procurement requirements. As in DEMO I, in

DEMO II there are some parameters which will be measured by the same equipment and thus no further procurement will be needed for these parameters. For the sake of completeness, further details are obtained regarding the possible suppliers for each one of the proposed equipment.

FINAL LIST OF EQUIPMENT						
DEMO	DEMO II	Industry	K-FLEX			
No.	Equipment type	Model	Quantity	Availability	Supplier	Parameters to measure
1a	Electrical power consumption meter	LUMEL NR32	1	YES	LUMEL	**P_X:** electrical power consumption in the process (MW)
1b	Electrical power consumption meter	Sonel MPI-540	1	NO	Sonel	**P_X:** electrical power consumption in the process (MW)
2	Laser Metter measure	SIKORA LASER 2100	1	YES	SIKORA	**D_o:** Outer diameter of the pipe (m)
3	Microscope	VHX-7000N	1	YES	Keyence microscope	**D_i:** Inner diameter of the pipe (m)
4	Dynamometer	Z005 TH1	1	YES	ZWICK Roell	***F*pull:** Adhesion of the different layers using a pulling rig **R:** thermal durability of the outer layer of pipe on the basis of resistance to cracking after aging in a dryer
5	Thermocamera	FLIR T335	1	YES	FLIR	**$T_{process}$:** Temperature achieved in the process (°C) **T_{max}**: Maximum temperature across the heated zone (ºC) **T_{max}**: Maximum temperature across the heated zone (ºC)
6a	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	NO	TSI	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
6b	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	NO	TSI	
7	Electromagnetic field meter	WAVECONTROL – SMP2	1	NO		$E_{inc} - Field_{measured}$ – incident electric field strength (volt per meter V.m^{-1})
No.	**Equipment type**	**Model**	**Quantity**	**Availability**	**Supplier**	**Parameters to measure**
8	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	NO	PCE instruments	$H_{inc} - Fie - d_{measured}$ – incident magnetic field strength (ampere per meter A.m^{-1})
9	Power meter or EMF meter	WAVECONTROL – SMP2	1	NO	WAVECONTROL	$S_{inc_{measured}}$ – incident power density (S_{inc}, watt per square meter, W.m^{-2})

10a	Sound level meter	SVAN 971	1	NO	SVANTEK	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.
10b	Sound level meter	DEM201	1	NO	Velleman	

Table 13: Final equipment list for DEMO II

After gathering all the essential information regarding the equipment required for monitoring the key parameters in the DEMO II case, it was crucial to define the main technical specifications of each model. To this end, the template presented in Table 10 was used as in DEMO I case. More specifically, CERTH reviewed all datasheets provided by the participating partners and extracted the core technical characteristics of each model. Table 14 summarizes the main specifications of the measurement equipment proposed for DEMO I. Additionally, a representative link is included for each item as in DEMO I case, offering access to the complete technical datasheet and further details beyond those listed in the "Main Features" column.

MAIN SPECIFICATIONS OF EQUIPMENT					
DEMO	DEMO II	**Industry**	K-FLEX		
No.	**Model**	**Main Features**		**Technical Datasheet**	**Supplier**
1a	LUMEL NR32	Measurement Range: Voltage: 100–400 V AC (phase-neutral), Current: 0.5–5 A (direct) / up to 6000 A (with CTs). Accuracy: Class 1 (per IEC 62053-21): ±1% for voltage/current, ±1.5% for active power. Parameters Measured: Voltage (L-N, L-L), current, active/reactive/apparent power, energy (kWh/kVARh), power factor, frequency. Communication: RS-485 (Modbus RTU protocol) for integration with SCADA/BMS systems. Display: LCD screen with backlight, shows real-time values + cumulative energy.		TDS [10]	LUMEL
1b	Sonel MPI-540	Measurement Range: 0 to 500 V AC/DC Frequency: 40 to 70 Hz Insulation Resistance: 50 kΩ to 10 GΩ Accuracy: ±2% ±2 digits (voltage) Resistance: ±2% ±3 digits Insulation: ±3% ±8 digits (0.1–10 GΩ) Safety Standards: Complies with IEC 61557 Ingress protection: IP51		TDS [11]	SONEL
2	SIKORA LASER 2100	Measurement Principle: Laser triangulation Diameter Range: 1–100 mm (round), 1-35 mm (sector) Accuracy: ±5.0 µm (round), ±20.0 µm (sector) Exposure time: 0.2 µsec		TDS [12][11]	SIKORA

		Measurement Speed: Up to 500 measurements/sec/axis Outputs: Ethernet/IP, Profibus-DP, RS-232		
3	VHX-7000N	Measurement Range: 10–2000 mm Accuracy: ±0.1 mm Sampling Rate: 2 kHz Outputs: Ethernet/IP, USB 2.0 and 3.0 series A Display: Colour LCD (IPS type), 27-inch Protection: IP67 (dust/waterproof)	TDS [13]	Keyence microscope
4	Z005 TH1	Force Range: up to 5 kN Speed Range: 0.0005–1500 mm/min Accuracy (Force): Class 0.5/1 (DIN EN ISO 7500-1) Test Space: Up to 1470 mm (height), up to 440 mm (width) Measured value recording rate: 400 kHz Outputs: Ethernet	TDS [14]	ZWICK Roell
5	FLIR Thermoca-mera E86 – 42°	Infrared Resolution: 464 × 348 pixels Temperature Range: -20°C to +650°C (extendable to +1500°C) Thermal Sensitivity: ≤0.03°C at 30°C Spectral Range: 7.5–14 µm Image frequency: 30 Hz Display: 4" touchscreen LCD	TDS [4]	GEASS

No.	Model	Main Features	Technical Datasheet	Supplier
6a	VelociCalc Air Velocity Meter TSI 9545-A	Velocity Range: 0–30 m/s Accuracy (Velocity): ±3% of reading (±0.015 m/s) Temperature Range: -10°C to +60°C Accuracy (Temperature): ±0.3°C Relative Humidity Range: 5 to 95% RH Accuracy (Relative Humidity): 0.1% RH Outputs: USB, Bluetooth	TDS [6]	TSI
6b	TSI Alnor TH-Calc 7415 or 7425	Temperature Range: -10°C to +60°C Accuracy (Temperature): ±0.6°C Relative Humidity Range: 5 to 95% RH Accuracy (Relative Humidity): ±3% RH Data Logging: SD card storage Logging Interval: 1 sec to 3600 sec	TDS [7]	TSI
7	WAVECONTROL – SMP2	Measurement Standards: Complies with EN 50160, IEC 61000-4-30 Class A Broadband: 0 Hz to 60 GHz (depending on field probe) Spectrum analysis: up to 400 kHz Measurable fields: E and H Memory capacity: >1 million samples Display: Color transmissive TFT (480 x 272 pixels)	TDS [15]	Wavecontrol
8	Magnometer PCE-EMF 30	Magnetic Field Range: 0.01–99.99 µT (DC/AC) Frequency Range: 5 Hz–100 kHz Resolution: 0.01 µT Accuracy: ±2% ±5 digits Power Supply & Battery Life: Rechargeable battery 3.7 V / 1,000 mAh, with auto power-off after 15 minutes of inactivity	TDS [8]	PCE instruments

		Protection: IP20		
9	WAVECONTROL – SMP2	Measurement Standards: Complies to EN 50160, IEC 61000-4-30 Class A Broadband: 0 Hz to 60 GHz (depending on field probe) Spectrum analysis: up to 400 kHz Measurable fields: E and H Memory capacity: >1 million samples Display: Color transmissive TFT (480 x 272 pixels)	TDS [15]	Wavecontrol
10a	SVAN 971	Measurement Range: 30 dB to 140 dB (covers whisper to jet-engine noise; auto-ranging). Frequency Range: 6.3 Hz to 20.0 kHz (extends to infrasound and ultrasonic ranges). Accuracy: ±0.5 dB (Class 1 per IEC 61672-1, highest precision standard). Weighting filters: A, B, C, Z, LF Display: Color 96 x 96 pixels OLED type	TDS [16]	SVANTEK
10b	DEM201	Measurement Range: 30–130 dB Frequency Range: 31.5 Hz–8 kHz Accuracy: ±1.4 dB Weighting Curves: A/C Display: LCD with backlight	TDS [9]	Velleman

Table 14: Equipment main specifications for DEMO II

4.3 Measuring equipment procurement and parameters monitoring

The measuring equipment was successfully determined, and the next step is to define which partner is going to be responsible for the procurement of the remaining necessary instrumentation and the parameters monitoring process in each case. This was essential to be clarified in order for each involved partner to know their exact contribution in the particular aspect of the present task. Hence, a deep discussion regarding this issue among the different parties involved was established and the responsibility was shared among the partners. For simplification reasons, the equipment which is not available and needed to be procured in each DEMO was gathered separately in a single list given in Table 15 and Table 16 respectively for each DEMO.

LIST OF NOT AVAILABLE EQUIPMENT						
DEMO	DEMO I	**Industry**	ART			
No.	**Equipment type**	**Model**	**Quantity**	**Availability**	**Supplier**	**Parameters to measure**
1	Electrical power consumption meter	EMA CONTREL 90N	2	NO	IDG / BIESSE	**P_X:** electrical power consumption in the process (MW) **$P_{PV,X}$**: PV electrical power in the process (MW)
2	Infrared thermometer	OPTRIS CT 3ML infrared thermometer	TBD	NO	Luchsinger	**$T_{process}$:** Temperature achieved in the process (°C) **T_{max}**: Maximum temperature across the heated zone (ºC) **T_{max}**: Maximum temperature across the heated zone (ºC)
3	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	NO	TSI	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
4	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	NO	TSI	
5	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	NO	PCE instru-ments	$B_{measured}$: Magnetic flux density in μT (measured)
6	Sound level meter	DEM201	1	NO	Velleman	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}{}^{Measured}$**:** Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.

Table 15: List of not available equipment in DEMO I

LIST OF NOT AVAILABLE EQUIPMENT						
DEMO	DEMO II	Industry	K-FLEX			
No.	Equipment type	Model	Quantity	Availability	Supplier	Parameters to measure
1	Electrical power consumption meter	Sonel MPI-540	1	NO	Sonel	**Px:** electrical power consumption in the process (MW)
2	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	NO	TSI	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
3	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	NO	TSI	
4	Electromagnetic field meter	WAVECONTROL – SMP2	1	NO		$E_{inc} - Field_{measured}$ – incident electric field strength (volt per meter $V.m^{-1}$)
5	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	NO	PCE instruments	$H_{inc} - Fie - d_{measured}$ – incident magnetic field strength (ampere per meter $A.m^{-1}$)
6	Power meter or EMF meter	WAVECONTROL – SMP2	1	NO	WAVE-CONTROL	$S_{inc_{measured}}$ – incident power density (S_{inc}, watt per square meter, $W.m^{-2}$)
7	Sound level meter	SVAN 971	1	NO	SVANTEK	$L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.
8	Sound level meter	DEM201	1	NO	Velleman	

Table 16: List of not available equipment in DEMO II

According to the tables provided above (Table 15 and Table 16) there are specific instruments/sensors and measuring devices which should be procured, deployed and used in each of the DEMO sites, to proceed with reliable and proper monitoring of the remaining key process-driven parameters need to be measured in each DEMO case, Hence, it is critical at this point to share properly the responsibilities regarding the procurement of the not already available equipment. For this reason, two detailed tables (Table 17 and Table 18) were created, each one for each demonstrator, in which a preliminary organization regarding the procurement responsibilities is presented.

PROCUREMENT AND MONITORING RESPONSIBLE					
DEMO	DEMO I	**Industry**	ART		
No.	**Equipment type**	**Model**	**Quantity**	**Procurement responsible**	**Parameters to measure**
1	Electrical power consumption meter	EMA CONTREL 90N	2	ART	**P_X:** electrical power consumption in the process (MW) **$P_{PV,X}$**: PV electrical power in the process (MW)
2	Infrared thermometer	OPTRIS CT 3ML infrared thermometer	TBD	ART	**$T_{process}$:** Temperature achieved in the process (°C) **T_{max}**: Maximum temperature across the heated zone (ºC) **T_{max}**: Maximum temperature across the heated zone (ºC)
3	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	ISQ	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
4	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	ISQ	
5	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	ISQ	$B_{measured}$: Magnetic flux density in µT (measured)
6	Sound level meter	DEM201	1	ISQ	$L_{EX,8h}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}^{Measured}$**:** Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.

Table 17: Procurement and monitoring responsible in DEMO I

PROCUREMENT RESPONSIBLE					
DEMO	DEMO II	Industry	K-FLEX		
No.	Equipment type	Model	Quantity	Procurement responsible	Parameters to measure
1	Electrical power consumption meter	Sonel MPI-540	1	K-FLEX	**P_X:** electrical power consumption in the process (MW)
2	Anemometer	VelociCalc Air Velocity Meter TSI 9545-A	1	ISQ	**TC:** Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature 5 checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials.
3	Thermohygro-anemometer	TSI Alnor TH-Calc 7415 or 7425	1	ISQ	
4	Electromagnetic field meter	WAVECONTROL – SMP2	1	ISQ	$\boldsymbol{E_{inc} - Field_{measured}}$ – incident electric field strength (volt per meter V.m^{-1})
5	Gaussmeter, Magnetometer	Magnometer PCE-EMF 30	1	ISQ	$\boldsymbol{H_{inc} - Fie - d_{measured}}$ – incident magnetic field strength (ampere per meter A.m^{-1})
6	Power meter or EMF meter	WAVECONTROL – SMP2	1	ISQ	$\boldsymbol{S_{inc_{measured}}}$ – incident power density (S_{inc}, watt per square meter, W.m^{-2})
7	Sound level meter	SVAN 971	1	K-FLEX	$\boldsymbol{L_{EX,8h}}^{\boldsymbol{Measured}}$: Worker level of exposure to noise measured using a decibel meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $\boldsymbol{p_{peak}}^{\boldsymbol{Measured}}$**:** Peak sound pressure measured using a sound level meter during an 8h worker shift of activities of induction and microwave heating systems in JOULIA project.
8	Sound level meter	DEM201	1	ISQ	

Table 18: Procurement responsible in DEMO II

As far as the procurement needs are concerned, it has to be mentioned that the indicated partners to be responsible for procurement in Table 17 and Table 18 have been selected after a preliminary organization regarding the procurement plan. The last one will be probably reconsidered during the progress of the project, focusing on the potential key interconnections of each partner with the relative marketplace.

As regards the monitoring procedure in each examined case, it is proposed that this responsibility should lie to each DEMO holder. Hence, ART will take the responsibility for monitoring all the key process-driven parameters in DEMO I listed in Table 7 and K-FLEX will be responsible for the respective parameters in DEMO II gathered in Table 8. It is important to mention here that the rest of the partners will play a supportive role in the monitoring process in each DEMO by having an active involvement in case this is necessary. Thus, the monitoring responsibilities will also be modified as the procurement ones during the project progress according to the contribution potential of each partner.

Conclusions and Discussion

In the present report, a comprehensive Key Performance Indicator (KPI)-based evaluation framework within the JOULIA project was established for the assessment of two new integrated heating systems demonstrated in two different industrial processes. In particular, an induction and a microwave heating system will be integrated into the industrial sites of ARTIGO and K-FLEX companies respectively to substitute (partially or totally) the existing conventional systems, aiming in the electrification of two specific processes. These processes regard rubber vulcanization in the ARTIGO case and multilayer pipe gluing in K-FLEX.

The main scope of the present deliverable was the **definition of suitable KPIs** for the evaluation of alternative integrated systems focusing on their technical, environmental, economic and social impact. Another important objective of the present report is the **determination of the key process-driven parameters** which are necessary for the KPIs' calculation as well as for achieving proper monitoring of the two systems. Apart from the KPIs and the key process-driven parameters definition, great emphasis was given to the **determination of the required measuring equipment** reporting the proposed equipment for measuring each parameter, the availability, the quantity needed, the main technical specifications of the proposed instrumentation, the potential suppliers and other important information for getting a detailed overview regarding the measuring equipment which is required and for ensuring proper and reliable monitoring of the systems' crucial factors.

A structured **methodology of five different steps** was developed and put forward for ensuring a comprehensive definition, calculation, and monitoring of the defined KPIs, supporting by this way the project's main goal which is none other than demonstrating measurable enhancement over the conventional heating systems by the implementation of the new heating technologies in the two DEMO sites. Four working teams were formed with each one to be dedicated in each KPI category (technical, environmental, economic, social) based on partner expertise, while several detailed templates were developed (KPIs cards, parameters lists, measuring equipment list, equipment specifications list etc.) for ensuring a consistent and organized procedure during the definition of the KPIs, the determination of the key process-driven parameters and the selection of the measuring instrumentation.

A critical achievement of this work is the comprehensive and in-depth delimitation of system boundaries in each DEMO case and the identification of the most relevant KPIs according to the unique characteristics of each industrial process and each integrated system. Both the transition from diathermic oil heating (with NG burners) to the induction system in ARTIGO and the replacement of the electric heating elements with the microwave heating system in K-FLEX, correspond to substantial modifications in both the rubber vulcanization and the multilayer pipe gluing processes. Hence, the impact assessment framework regarding the specific modifications is accompanied by great challenges and it should be treated carefully, including multiple perspectives.

Moreover, the detailed determination of the key process-driven parameters and the selection of the required measuring equipment, along with the clarification of partner responsibilities regarding procurement and monitoring, ensures the accuracy and reliability of the data to be collected during the demonstration phase. This aspect is of great importance for achieving credible and comparable conclusions between the baseline and the upgraded scenarios during the assessment stage.

Despite the well-established and organized methodological approach which was followed in this work, the KPI selection procedure remains challenging due to the several different and interdependent factors

which affect the industrial process. The need to balance technical relevance, environmental significance, economic feasibility, and social implications requires continuous engagement among the stakeholders. Nonetheless, the framework established here provides the necessary flexibility and robustness to accommodate these complexities and to support meaningful assessment of outcomes.

To sum up, this deliverable establishes a solid foundation for the upcoming evaluation activities in the JOULIA project. It ensures that the benefits of the induction and microwave heating technologies in terms of energy efficiency gain, environmental impact reduction, industrial competitiveness and social impact, can be quantitatively demonstrated and evaluated. Additionally, the established framework supports the scalability and the potential of the adoption to wider applications that involve the proposed technologies even across other energy-intensive sectors, contributing to the broader goals of industrial decarbonization and sustainable development.

Future work will focus on the real-time monitoring and analysis of the demonstration results, validation of the defined KPIs against actual process data, and the interpretation of findings considering industrial applicability and energy policy relevance. The outcomes of this effort are expected to provide valuable insights not only for the JOULIA partners but also for the wider industrial and research communities promoting pathways to energy-efficient and low-carbon manufacturing processes.

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Annex - KPIs' cards

Annex I - Technical KPIs

KPI's CARD / T-KPI-01												
MAIN INFORMATION												
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**					
KPI's Code	T-KPI-01											
KPI's Name	Temperature to Energy ratio											
KPI's Description	This KPI measures the efficiency of energy input in the system by evaluating the achieved process temperature per unit of input energy. It provides insight into the effectiveness of the heating system in achieving the required temperature levels.											
KPI's Symbol	TER											
KPI's Units	°C/kWh											
KPI's Determination Type	**Calculation**				**Measurement**	X						
KPI's Formula	$TER = \frac{T_{process}}{E_{Input,X}}$ Where: $E_{input,X} = E_{th,input,B}$ or $E_{el,input,U}$ $E_{th,input,B} = \int_0^t \dot{m}_{th.oil} \cdot c_{p,th.oil} \cdot (T_{in,th.oil} - T_{out,th.oil}) dt$ $E_{el,input,U} = \int_0^t P_X \, dt$											
KPI's formula's parameters' explanation	**$T_{process}$:** Temperature achieved in the process (°C) **$E_{input,X}$:** Total energy input (MWh) **$E_{th,input,B}$:** thermal energy input in the baseline process - (MWh_{th}) **$E_{el,input,U}$:** annual electrical energy input in the upgraded process - (MWh_{el}) **$T_{in,th.oil}$:** Thermal oil inlet temperature (°C) **$T_{out,th.oil}$:** Thermal oil outlet temperature (°C) **$\dot{m}_{th.oil}$:** Mass flow rate of thermal oil (kg/s) **$c_{p,th.oil}$:** Specific heat capacity of water (kJ/kg/K) **P_X:** electrical power consumption in the process (MW)											
KPI's parameters to be measured	$T_{process}$, $\dot{m}_{th.oil}$, $T_{in,th.oil}$, $T_{out,th.oil}$, P_X											
KPI's parameters to be calculated	$E_{th,input,B}$, $E_{el,input,U}$											
KPI's parameters to be found or estimated	$c_{p,th.oil}$											
OTHER INFORMATION												
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**			**IS-2**			**All**	X				
KPI's correspondence (Case under evaluation)	**Baseline Scenario (BS)**			**Upgraded Scenario (US)**			**All**	X				
KPI's Calculation Responsible	CIRCE											

Table 19: Temperature to Energy ratio (T-KPI-01)

KPI's CARD / T-KPI-02

MAIN INFORMATION										
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**			
KPI's Code	T-KPI-02									
KPI's Name	Energy consumption per mass produced									
KPI's Description	This KPI measures the amount of thermal or electrical energy consumed per unit mass of material processed. It provides a normalized metric to compare the energy efficiency of heating systems when processing the same amount of material.									
KPI's Symbol	SEC									
KPI's Units	kWh/kg									
KPI's Determination Type	**Calculation**	X			**Measurement**					
KPI's Formula	$SEC = \frac{E_{input,X}}{M}$ Where: $E_{input,X} = E_{th,input,B}$ or $E_{el,input,U}$ $E_{th,input,B} = \int_0^t \dot{m}_{th.oil} \cdot c_{p,th.oil} \cdot (T_{in,th.oil} - T_{out,th.oil})dt$ $E_{el,input,U} = \int_0^t P_X \, dt$ $M = \rho \cdot TH \cdot W \cdot \int_0^t u \, dt$ or $M = \rho \cdot \frac{\pi \cdot (D_O^2 - D_i^2)}{4} \cdot \int_0^t u \, dt$									
KPI's formula's parameters' explanation	**$E_{input,X}$:** Total energy input (MWh) **$E_{th,input,B}$:** thermal energy input in the baseline process from time moment "0" to time moment "t"- (MWh_{th}/year) **$E_{el,input,U}$:** electrical energy input in the upgraded process from time moment "0" to time moment "t"- (MWh_{el}/year) **$T_{in,th.oil}$:** Thermal oil inlet temperature **$T_{out,th.oil}$:** Thermal oil outlet temperature **$\dot{m}_{th.oil}$:** Mass flow rate of thermal oil (kg/s) **$c_{p,th.oil}$:** Specific heat capacity of water (kJ/kg/K) **P_X:** Electrical power consumption in the process (MW) **M:** Mass of the produced product from time moment "0" to "t" (kg) **ρ:** Density of the floor material or the pipe material (kg/m^3) **TH:** Thickness of the floor produced (m) **W:** Width of the floor produced (m) **D_i:** Inner diameter of the pipe (m) **D_o:** Outer diameter of the pipe (m) **u:** Velocity of the floor or the pipe (m/s)									
KPI's parameters to be measured	$\dot{m}_{th.oil}$, $T_{in,th.oil}$, $T_{out,th.oil}$, P_X, TH, W, D_i, D_o, u									
KPI's parameters to be calculated	$E_{th,input,B}$, $E_{el,input,U}$, M									
KPI's parameters to be found or estimated	$c_{p,th.oil}$, ρ									
OTHER INFORMATION										
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X				
KPI's correspondence (Case under evaluation)	**Baseline Scenario (BS)**		**Upgraded Scenario (US)**		**All**	X				
KPI's Calculation Responsible	CIRCE									

Table 20: Energy consumption per mass produced (T-KPI-02)

KPI's CARD / T-KPI-03								
MAIN INFORMATION								
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**	
KPI's Code	T-KPI-03							
KPI's Name	Temperature Uniformity Index							
KPI's Description	This KPI measures the temperature uniformity in the heating process. It quantifies the difference between maximum and minimum temperatures relative to the average temperature across the heated zone. A lower TUI indicates a more uniform temperature distribution, ensuring consistent material properties.							
KPI's Symbol	TUI							
KPI's Units	%							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$\mathrm{TUI} = \frac{T_{max} - T_{min}}{T_{avg}}$							
KPI's formula's parameters' explanation	$\mathbf{T_{max}}$: the maximum temperature across the heated zone (ºC) $\mathbf{T_{min}}$: the minimum temperature across the heated zone (ºC) $\mathbf{T_{avg}}$: the average temperature across the heating zone, obtained making the mean of all the measurement points (ºC)							
KPI's parameters to be measured	T_{max} T_{min}							
KPI's parameters to be calculated	T_{avg}							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**ALL**	X		
KPI's correspondence **(Case under evaluation)**	**Baseline Scenario (BS)**		**Upgraded Scenario (US)**		**ALL**	X		
KPI's Calculation Responsible	CIRCE							

Table 21: Temperature uniformity Index (T-KPI-03)

MAIN INFORMATION								
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**	
KPI's Code	T-KPI-04							
KPI's Name	Magnetic Field Distribution Uniformity							
KPI's Description	This KPI quantifies the uniformity of the magnetic field distribution within the heating area. A more uniform magnetic field leads to consistent heating, which is critical for proper vulcanization of rubber. A lower value indicates better uniformity.							
KPI's Symbol	CV_B							
KPI's Units	%							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$CV_B = \frac{\sigma_B}{\mu_B}$							
KPI's formula's parameters' explanation	$\boldsymbol{\sigma_B}$: Standard deviation of the magnetic field strength (A/m or T) $\boldsymbol{\mu_B}$: mean magnetic field strength (A/m or T)							
KPI's parameters to be measured	T_{max} T_{min}							
KPI's parameters to be calculated	-							
KPI's parameters to be found or estimated	σ_B μ_B							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**	X	**IS-2**		**All**			
KPI's correspondence **(Case under evaluation)**	**Baseline Scenario (BS)**		**Upgraded Scenario (US)**	X	**All**			
KPI's Calculation Responsible	ART							

Table 22: Magnetic Field Distribution Uniformity - Induction Heating (T-KPI-04)

KPI's CARD / T-KPI-05								
MAIN INFORMATION								
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**	
KPI's Code	T-KPI-05							
KPI's Name	Antenna/Cavity Tuning Accuracy and Responsiveness							
KPI's Description	This KPI quantifies the uniformity of the magnetic field distribution within the heating area. A more uniform magnetic field leads to consistent heating, which is critical for proper pipe multilayer gluing. A lower value indicates better uniformity.							
KPI's Symbol	Δf							
KPI's Units	Hz							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$\Delta f = \lvert f_{target} - f_{actual} \rvert$							
KPI's formula's parameters' explanation	$\mathbf{f_{target}}$: Desired (target) frequency of operation (Hz) $\mathbf{f_{actual}}$: Actual frequency of operation (Hz)							
KPI's parameters to be measured	f_{actual}							
KPI's parameters to be calculated	f_{target}							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**	X	**All**			
KPI's correspondence (Case under evaluation)	**Baseline Scenario (BS)**		**Upgraded Scenario (US)**	X	**All**			
KPI's Calculation Responsible	K-FLEX							

Table 23: Antenna/Cavity Tuning Accuracy and Responsiveness - Microwave Heating (T-KPI-05)

KPI's CARD / T-KPI-06												
MAIN INFORMATION												
KPI's Type	**Technical**	**X**	**Environmental**		**Economical**		**Social**					
KPI's Code	T-KPI-06											
KPI's Name	Process Temperature Repeatability / Stability											
KPI's Description	This KPI quantifies how consistently the system maintains its temperature over time under continuous operation. A lower coefficient of variation indicates better process stability, meaning less fluctuation in temperature and more reliable performance.											
KPI's Symbol	$T_{Stability}$											
KPI's Units	Celsius (ºC)											
KPI's Determination Type	**Calculation**	X	**Measurement**									
KPI's Formula	$T_{Stability} = \frac{\sigma_{steady-state}}{\mu_{steady-state}}$											
KPI's formula's parameters' explanation	$\boldsymbol{\sigma_{steady-state}}$: Standard deviation of temperature (°C) during steady-state operation $\boldsymbol{\mu_{steady-state}}$: Mean temperature (°C) during steady-state operation											
KPI's parameters to be measured	-											
KPI's parameters to be calculated	$\boldsymbol{\sigma_{steady-state}}$ $\boldsymbol{\mu_{steady-state}}$											
KPI's parameters to be found or estimated	-											
OTHER INFORMATION												
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**			**IS-2**			**All**	X				
KPI's correspondence **(Case under evaluation)**	**Baseline Scenario (BS)**			**Upgraded Scenario (US)**			**All**	X				
KPI's Calculation Responsible												

Table 24: Process Repeatability / Stability (T-KPI-06)

Annex II - Environmental KPIs

KPI CARD / ENV-KPI-01								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**	
KPI's Code	**ENV-KPI-01**							
KPI's Name	Operational GHG emissions (Annual)							
KPI's Description	This KPI measures the GHG emissions during the annual operation of the system.							
KPI's Symbol	$O^{(i)}_{GHG,X}$							
KPI's Units	$t_{CO2\text{-}eq}$/year							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$O^{(i)}_{GHG,X} = O^{(i)}_{GHG,\,MN,X} + O^{(i)}_{GHG,\,FI,X}$, where: $O^{(i)}_{GHG,\,FI,X} = FI^{(i)}_{el,X} \cdot EF_{el} + \sum_{\forall k \in Fuel\ Types} FI^{(i)}_{k,X} \cdot EF_k$ $FI^{(i)}_{k,X} = \frac{E^{(i)}_{th,input,X}}{\eta_{boiler} \cdot \eta_{loss,piping}}$, $E_{th,input,X} = \int_0^t \dot{m}_{th.oil} \cdot c_{p,th.oil} \cdot (T_{in,th.oil} - T_{out,th.oil})dt$ $FI^{(i)}_{el,X} = FE^{(i)}_{el,X} - E^{(i)}_{el,PV,X}$, $FE^{(i)}_{el,X} = E^{(i)}_{el,input,X}$, $E^{(i)}_{el,input,X} = \int_0^t P_X dt$ $O^{(i)}_{GHG,\,MN,X} = \sum_{\forall j \in Components} O^{(i)}_{GHG,\,MN,X,j}$							
KPI's formula's parameters' explanation	$O^{(i)}_{GHG,\,MN,X}$: annual GHG emissions for maintenance in year "i" - ($t_{CO2\text{-}eq}$/year) $O^{(i)}_{GHG,\,FI,X}$: annual GHG emissions from electrical and non-electrical fuel consumption in year "i"- ($t_{CO2\text{-}eq}$/year) $O^{(i)}_{GHG,\,MN,X,j}$: annual GHG emissions for the maintenance of component "j" for year "i" - ($t_{CO2\text{-}eq}$/year) $FI^{(i)}_{k,X}$: annual energy amount of the imported fuel in year "i"- (MWh_{FI}/year) $E^{(i)}_{th,input,X}$: annual thermal energy input in the process in year "i" - (MWh_{th}/year) η_{boiler}: NG boiler efficiency $\eta_{loss,piping}$: Thermal loss piping efficiency $T_{in,th.oil}$: Thermal oil inlet temperature (°C) $T_{out,th.oil}$: Thermal oil outlet temperature (°C) $\dot{m}_{th.oil}$: Mass flow rate of thermal oil (kg/s) $c_{p,th.oil}$: Specific heat capacity (kJ/kg/K) $FI^{(i)}_{el,X}$: annual amount of the imported electricity in the process in year "i"- (MWh_{el}/year) $FE^{(i)}_{el,X}$, $E^{(i)}_{el,input,X}$: annual electrical final energy input in the process in year "i" - (MWh_{el}/year) $E^{(i)}_{el,PV,X}$: annual electrical energy from PVs to the process in year "i", (MWh_{el}) P_X: electrical power consumption in the process (MW) $P_{PV,X}$: PV electrical power in the process (MW) EF_k: emissions factor corresponding to "k" fuel - ($t_{CO2\text{-}eq}/t_{FI}$ or $t_{CO2\text{-}eq}/MWh_{th}$) EF_{el}: emissions factor corresponding to electricity - ($t_{CO2\text{-}eq}/t_{FI}$ or $t_{CO2\text{-}eq}/MWh_{el}$) X: indicator for baseline (B) or upgraded scenario (U) k: indicator for the type of the fuel or source of energy used (e.g. natural gas)							
KPI's parameters to be measured	$\dot{m}_{th.oil}$, $T_{in,th.oil}$, $T_{out,th.oil}$, P_X, $P_{PV,X}$							
KPI's parameters to be calculated	$O^{(i)}_{GHG,\,FI,X}$, $FI^{(i)}_{k,X}$, $FI^{(i)}_{el,X}$, $E^{(i)}_{th,input,X}$, $FE^{(i)}_{el,X}$, $E^{(i)}_{el,input,X}$, $E^{(i)}_{el,PV,X}$							
KPI's parameters to be found or estimated	$O^{(i)}_{GHG,\,MN,X}$, EF_k, EF_{el}, η_{boiler}, $\eta_{loss,piping}$, $c_{p,th.oil}$							

OTHER INFORMATION						
Integrated System (IS)* **IS-1: IND heating, IS-2: MW heating*	**IS-1**		**IS-2**		**All**	X
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X
KPI's Calculation Responsible	CERTH					

Table 25: Annual Operational GHG Emissions (ENV-KPI-01)

KPI CARD / ENV-KPI-02								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**	
KPI's Code	**ENV-KPI-02**							
KPI's Name	Operational GHG Emissions Reduction (Annual)							
KPI's Description	This KPI measures the percentage reduction of the GHG emissions which is achieved during the whole system's annual operation due to the integration of the new component (comparison between the baseline and the upgraded scenario)							
KPI's Symbol	$\mathrm{Em}_{\mathrm{r}}^{(\mathrm{i})}$							
KPI's Units	%							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$$\mathrm{Em}_{\mathrm{r}}^{(\mathrm{i})} = \frac{\mathrm{O}_{\mathrm{GHG,B}}^{(\mathrm{i})} - \mathrm{O}_{\mathrm{GHG,U}}^{(\mathrm{i})}}{\mathrm{O}_{\mathrm{GHG,B}}^{(\mathrm{i})}}$$							
KPI's formula's parameters' explanation	$\mathbf{O}_{\mathbf{GHG,B}}^{(\mathbf{i})}$**:** annual operational GHG emissions for the baseline scenario (B) in year "i"- ($t_{CO2\text{-}eq}$/year) $\mathbf{O}_{\mathbf{GHG,U}}^{(\mathbf{i})}$**:** annual operational GHG emissions for the upgraded scenario (U) in year "i" - ($t_{CO2\text{-}eq}$/year)							
KPI's parameters to be measured	-							
KPI's parameters to be calculated	$\mathrm{O}_{\mathrm{GHG,B}}^{(\mathrm{i})}$, $\mathrm{O}_{\mathrm{GHG,U}}^{(\mathrm{i})}$							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X		
KPI's Calculation Responsible	CERTH							

Table 26: Annual Operational GHG Emissions Reduction (ENV-KPI-02)

KPI CARD / ENV-KPI-03								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**	
KPI's Code	**ENV-KPI-03**							

KPI's Name	Operational Primary Energy (PE) Consumption (Annual)						
KPI's Description	This KPI measures the annual PE consumption of the process in which the new system will be integrated.						
KPI's Symbol	$O_{PE,X}^{(i)}$						
KPI's Units	MWh_{PE}/year						
KPI's Determination Type	**Calculation**	X	**Measurement**				
KPI's Formula	$O_{PE,X}^{(i)} = O_{PE,\,MN,X}^{(i)} + O_{PE,\,FE,X}^{(i)}$ Where: $O_{PE,FE,X}^{(i)} = FE_{el,X}^{(i)} \cdot PEF_{el} + \sum_{\forall k \in Fuel\ Types} \left(FE_{k,X}^{(i)} \cdot PEF_{k}\right)$ $FE_{el,X}^{(i)} = E_{el,input,X}^{(i)}$ $E_{el,input,X}^{(i)} = \int_{0}^{t} P_X\, dt$ $O_{PE,\,MN,X}^{(i)} = \sum_{\forall j \in Components} O_{PE,\,MN,X,j}^{(i)}$							
KPI's formula's parameters' explanation	**X:** indicator for baseline (B) or upgraded scenario (U) **k:** indicator for the type of the fuel (natural gas, oil, biomass etc.) $\mathbf{FE_{k,X}^{(i)}}$**:** annual final energy of fuel type "k" consumed in the process in year "i" - (MWh_{FE}/year) $\mathbf{FE_{el,X}^{(i)}}$, $\mathbf{E_{el,input,X}^{(i)}}$**:** annual electrical final energy input in the process in year "i" - (MWh_{el}/year) $\mathbf{P_X}$**:** electrical power consumption in the process (MW) $\mathbf{PEF_k}$**:** primary energy factor corresponding to fuel type "k" - (MWh_{PE}/ MWh_{FE}) $\mathbf{PEF_{el}}$**:** primary energy factor corresponding to electricity - (MWh_{PE}/ MWh_{FE}) $\mathbf{O_{PE,\,FE,X}^{(i)}}$**:** annual PE consumed for the process in year "i" - ($t_{CO2\text{-}eq}$/year) $\mathbf{O_{PE,\,MN,X}^{(i)}}$**:** annual PE consumed for the maintenance of all the components in year "i" - ($t_{CO2\text{-}eq}$/year) $\mathbf{O_{PE,\,MN,X,j}^{(i)}}$**:** annual PE consumed for the maintenance of component "j" in year "i" - ($t_{CO2\text{-}eq}$/year)							
KPI's parameters to be measured	P_X						
KPI's parameters to be calculated	$FE_{el,X}^{(i)}$, $FE_{k,X}^{(i)}$						
KPI's parameters to be found or estimated	PEF_{el}, PEF_{k}						
OTHER INFORMATION							
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X	
KPI's correspondence **(Case under evaluation)**	**Baseline**		**Upgraded**		**All**	X	
KPI's Calculation Responsible	CERTH						

Table 27: Annual Operational Primary Energy (PE) Demand (ENV-KPI-03)

KPI CARD / ENV-KPI-04								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**	
KPI's Code	**ENV-KPI-04**							
KPI's Name	Operational Primary Energy (PE) Consumption Reduction (Annual)							

KPI's Description	This KPI measures the average percentage reduction of the primary energy consumption which is achieved during the whole system's annual operation due to the integration of the new component (comparison between the baseline and the upgraded scenario)					
KPI's Symbol	$PE_r^{(i)}$					
KPI's Units	%					
KPI's Determination Type	**Calculation**	X	**Measurement**			
KPI's Formula	$PE_r^{(i)} = \frac{O_{PE,B}^{(i)} - O_{PE,U}^{(i)}}{O_{PE,B}^{(i)}}$					
KPI's formula's parameters' explanation	$\mathbf{O_{PE,B}^{(i)}}$: annual operational PE demand for the baseline scenario (B) in year "i" - (MWh_{PE}/year) $\mathbf{O_{PE,U}^{(i)}}$: annual operational PE demand for the upgraded scenario (U) in year "i" - (MWh_{PE}/year)					
KPI's parameters to be measured	-					
KPI's parameters to be calculated	$O_{PE,B}^{(i)}$, $O_{PE,U}^{(i)}$					
KPI's parameters to be found or estimated	-					
OTHER INFORMATION						
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X
KPI's Calculation Responsible	CERTH					

Table 28: Annual Operational Primary Energy (PE) Demand Reduction (ENV-KPI-04)

KPI CARD / ENV-KPI-05									
MAIN INFORMATION									
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**		
KPI's Code	**ENV-KPI-05**								
KPI's Name	Fossil Fuel Reduction (Annual)								
KPI's Description	This KPI measures the average percentage reduction of the fossil fuel which is achieved during the whole system's annual operation due to the integration of the new component (comparison between the baseline and the upgraded scenario)								
KPI's Symbol	$FF_r^{(i)}$								
KPI's Units	%								
KPI's Determination Type	**Calculation**	X	**Measurement**						
KPI's Formula	$FF_r^{(i)} = \frac{O_{FF,B}^{(i)} - O_{FF,U}^{(i)}}{O_{FF,B}^{(i)}}$								
KPI's formula's parameters' explanation	$\mathbf{O_{FF,B}^{(i)}}$**:** annual operational Fossil Fuel consumption for the baseline scenario (B) in year "i"- (t_{FF}/year) $\mathbf{O_{FF,U}^{(i)}}$**:** annual operational Fossil Fuel consumption for the upgraded scenario (U) in year "i"- (t_{FF}/year)								
KPI's parameters to be measured	-								
KPI's parameters to be calculated	$O_{FF,B}^{(i)}$, $O_{FF,U}^{(i)}$								
KPI's parameters to be found or estimated	-								
OTHER INFORMATION									
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**				**All**	X	
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**				**All**	X	
KPI's Calculation Responsible	CERTH								

Table 29: Annual Fossil Fuel Reduction (ENV-KPI-05)

KPI CARD / ENV-KPI-06								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**	
KPI's Code	**ENV-KPI-06**							
KPI's Name	Lifetime Green House Gasses (GHG) Emissions							
KPI's Description	The Lifecycle GHG emissions is a critical environmental KPI that measures the total greenhouse gas (GHG) emissions produced throughout the lifecycle of the system.							
KPI's Symbol	$L_{GHG,U}$							
KPI's Units	$t_{CO2\text{-}eq}$							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$L_{GHG,U} = I^{(0)}_{GHG,U} + \sum_{i=1}^{N} O^{(i)}_{GHG,U}$							
KPI's formula's parameters' explanation	$\mathbf{I^{(0)}_{GHG,U}}$**:** GHG emissions from renovation (stage A and C emissions of the upgraded system (manufacturing, transportation, installation, decommission, end-of-life)) - ($t_{CO2\text{-}eq}$) **N:** the expected lifetime of the system - (years) $\mathbf{O^{(i)}_{GHG,U}}$**:** annual GHG emissions during the operation of the new integrated system (upgraded scenario) for year "i" - ($t_{CO2\text{-}eq}$/year)							
KPI's parameters to be measured	-							
KPI's parameters to be calculated	$I^{(0)}_{GHG,U}$, $O^{(i)}_{GHG,U}$							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**			**All**	X	
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X		**All**		
KPI's Calculation Responsible	CERTH							

Table 30: Lifetime GHG Emissions (ENV-KPI-06)

KPI CARD / ENV-KPI-07									
MAIN INFORMATION									
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**		
KPI's Code	**ENV-KPI-07**								
KPI's Name	Lifetime Primary Energy (PE) Demand								
KPI's Description	This KPI measures the PE demand of the process in which the new system will be integrated during its lifetime.								
KPI's Symbol	$L_{PE,U}$								
KPI's Units	MWh_{PE}								
KPI's Determination Type	**Calculation**	X	**Measurement**						
KPI's Formula	$L_{PE,U} = I^{(0)}_{PE,U} + \sum_{i=1}^{N} O^{(i)}_{PE,U}$								
KPI's formula's parameters' explanation	$\mathbf{I^{(0)}_{PE,U}}$**:** PE demand for renovation (stage A and C emissions of the upgraded system (manufacturing, transportation, installation, decommission, end-of-life)) – (MWh_{PE}) **N:** the expected lifetime of the system – (years) $\mathbf{O^{(i)}_{PE,U}}$**:** annual PE demand during the operation of the new integrated system (upgrade scenario) for year "i" – (MWh_{PE}/year)								
KPI's parameters to be measured	-								
KPI's parameters to be calculated	$I^{(0)}_{PE,U}$, $O^{(i)}_{PE,U}$								
KPI's parameters to be found or estimated	-								
OTHER INFORMATION									
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**			**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X		**All**			
KPI's Calculation Responsible	CERTH								

Table 31: Lifetime Primary Energy (PE) Demand (ENV-KPI-07)

KPI CARD / ENV-KPI-08												
MAIN INFORMATION												
KPI's Type	**Technical**		**Environmental**	X	**Economic**		**Social**					
KPI's Code	**ENV-KPI-08**											
KPI's Name	GHG Emissions Payback Period											
KPI's Description	This KPI indicates the years of operation required in order the accumulative savings to compensate the GHG emissions incurred due to the installation and operation of the system.											
KPI's Symbol	$T_{P,GHG}$											
KPI's Units	years											
KPI's Determination Type	**Calculation**	X	**Measurement**									
KPI's Formula	$T_{P,GHG} = T_{L,GHG} + t_{r,GHG}$ $t_{r,GHG} = \frac{I_{GHG,U}^{(0)} - \sum_{i=1}^{T_{L,GHG}} \left(O_{GHG,B}^{(i)} - O_{GHG,U}^{(i)}\right)}{O_{GHG,B}^{(T_{L,GHG}+1)} - O_{GHG,U}^{(T_{L,GHG}+1)}}$											
KPI's formula's parameters' explanation	$T_{L,GHG}$: The last period just before GHG emissions from renovation will be compensated by the accumulative operational savings - (years) $t_{r,GHG}$: The additional fraction of the year following $T_{L,GHG}$ when the compensation occurs. It indicates the part of year "$T_{L,GHG}$+1" in which the accumulative operational savings become equal to GHG emissions from renovation – (years) $I_{GHG,U}^{(0)}$: GHG emissions from renovation in year "0" – ($t_{CO2\text{-}eq}$) $O_{GHG,B}^{(i)}$: Annual operational GHG emissions of the baseline system in year i - ($t_{CO2\text{-}eq}$/year) $O_{GHG,U}^{(i)}$: Annual operational GHG emissions of the upgraded system in year i - ($t_{CO2\text{-}eq}$/year)											
KPI's parameters to be measured	-											
KPI's parameters to be calculated	$T_{L,GHG}$, $t_{r,GHG}$, $I_{GHG,U}^{(0)}$, $O_{GHG,B}^{(i)}$, $O_{GHG,U}^{(i)}$											
KPI's parameters to be found or estimated	-											
OTHER INFORMATION												
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**				**All**	X				
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X			**All**					
KPI's Calculation Responsible	CERTH											

Table 32: GHG Emissions Payback Period (ENV-KPI-08)

Annex III – Economic KPIs

KPI CARD / EC-KPI-01												
MAIN INFORMATION												
KPI's Type	**Technical**		**Environmental**	X	**Economical**		**Social**					
KPI's Code	**EC-KPI-01**											
KPI's Name	Capital Expenditure (CAPEX)											
KPI's Description	Includes the cost of equipment, the installation cost and the infrastructure upgrades cost regarding the new integrated system											
KPI's Symbol	$I_{C,U}^{(0)}$											
KPI's Units	€											
KPI's Determination Type	**Calculation**	X	**Measurement**									
KPI's Formula	$I_{C,U}^{(0)} = I_{C,U,equipment}^{(0)} + I_{C,U,transportation}^{(0)} + I_{C,U,installation}^{(0)} + I_{C,U,modifications}^{(0)}$											
KPI's formula's parameters' explanation	$I_{C,U,transportation}^{(0)}$: Transportation costs $I_{C,U,equipment}^{(0)}$: Cost of equipment (€). $I_{C,U,installtion}^{(0)}$: Installation Cost (€). $I_{C,U,modifications}^{(0)}$: Infrastructure Upgrades Cost - modifications cost (€).											
KPI's parameters to be measured	-											
KPI's parameters to be calculated	$I_{C,U,equipment}^{(0)}$, $I_{C,U,transportation}^{(0)}$, $I_{C,U,installtion}^{(0)}$, $I_{C,U,modifications}^{(0)}$											
KPI's parameters to be found or estimated	-											
OTHER INFORMATION												
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X						
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X	**All**							
KPI's Calculation Responsible	CORE											

Table 33: Capital Expenditure - CAPEX (EC-KPI-01)

KPI CARD / EC-KPI-02								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economical**		**Social**	
KPI's Code	**EC-KPI-02**							
KPI's Name	Relative CAPEX							
KPI's Description	It is the CAPEX of the new integrated system divided by the total installed power of the last one.							
KPI's Symbol	$I^{(0)}_{C,rel,U}$							
KPI's Units	€/kW							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$I^{(0)}_{C,rel,U} = \frac{I^{(0)}_{C,U}}{IP_U}$ **Subscripts:** C: cost rel: Relative **Superscripts:** 0: Year "0" when the new system is installed							
KPI's formula's parameters' explanation	$I^{(0)}_{C,U}$: CAPEX (see EC-KPI-01) IP_U: Installed power of the new system installed							
KPI's parameters to be measured	-							
KPI's parameters to be calculated	$I^{(0)}_{C,U}$							
KPI's parameters to be found or estimated	IP_U							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X	**All**			
KPI's Calculation Responsible	CORE							

Table 34: Relative CAPEX (EC-KPI-02)

KPI CARD / EC-KPI-03												
MAIN INFORMATION												
KPI's Type	**Technical**		**Environmental**	X	**Economical**		**Social**					
KPI's Code	**EC-KPI-03**											
KPI's Name	Operational Expenditure (OPEX) (Annual)											
KPI's Description	Expenses regarding the system's annual operation. Often abbreviated as OpEx.											
KPI's Symbol	$O_{C,X}^{(i)}$											
KPI's Units	€/year											
KPI's Determination Type	**Calculation**	X	**Measurement**									
KPI's Formula	$O_{C,X}^{(i)} = O_{C,MN,X}^{(i)} + O_{C,FI,X}^{(i)}$ Where: $O_{C,MN,X}^{(i)} = \sum_{\forall j \in Components} O_{C,MN,X,j}^{(i)}$, $O_{C,FI,X}^{(i)} = FI_{el,X}^{(i)} \cdot FC_{el,X}^{(i)} + \sum_{\forall k \in Fuel\ Types} FI_{k,X}^{(i)} \cdot FC_{k,X}^{(i)}$ $FI_{k,X}^{(i)} = \frac{E_{th,input,X}^{(i)}}{\eta_{boiler} \cdot \eta_{loss,piping}}$, $E_{th,input,X} = \int_0^t \dot{m}_{th.oil} \cdot c_{p,th.oil} \cdot (T_{in,th.oil} - T_{out,th.oil}) dt$ $FI_{el,X}^{(i)} = FE_{el,X}^{(i)} - E_{el,PV,X}^{(i)}$, $FE_{el,X}^{(i)} = E_{el,input,X}^{(i)}$, $E_{el,input,X}^{(i)} = \int_0^t P_X dt$, $E_{el,PV,X}^{(i)} = \int_0^t P_{PV,X} dt$											
KPI's formula's parameters' explanation	$O_{C,MN,X}^{(i)}$: The maintenance costs of the integrated system in year i (€/year); $O_{C,FI,X}^{(i)}$: The fuel (including electricity) consumption costs in year *i* (€/year); $FI_{k,X}^{(i)}$: annual energy amount of the imported fuel in year "i"- (MWh_{FI}/year) $E_{th,input,X}^{(i)}$: annual thermal energy input in the process in year "i" - (MWh_{th}/year) η_{boiler}: NG boiler efficiency $\eta_{loss,piping}$: Thermal loss piping efficiency $T_{in,th.oil}$: Thermal oil inlet temperature (°C) $T_{out,th.oil}$: Thermal oil outlet temperature (°C) $\dot{m}_{th.oil}$: Mass flow rate of thermal oil (kg/s) $c_{p,th.oil}$: Specific heat capacity (kJ/kg/K) $FI_{el,X}^{(i)}$: annual amount of the imported electricity in the process in year "i"- (MWh_{el}/year) $FE_{el,X}^{(i)}$, $E_{el,input,X}^{(i)}$: annual electrical final energy input in the process in year "i"(MWh_{el}/year) $E_{el,PV,X}^{(i)}$: annual electrical energy from PVs to the process in year "i", (MWh_{el}) P_X: electrical power consumption in the process (MW) $P_{PV,X}$: PV electrical power in the process (MW) $FC_{k,X}^{(i)}$: The average cost per MWh for the imported fuel for fuel type "k" in year i (€/MWh);											
KPI's parameters to be measured	$\dot{m}_{th.oil}$, $T_{in,th.oil}$, $T_{out,th.oil}$, P_X, $P_{PV,X}$											
KPI's parameters to be calculated	$O_{C,FI,X}^{(i)}$, $FI_{k,X}^{(i)}$, $FI_{el,X}^{(i)}$, $E_{th,input,X}^{(i)}$, $FE_{el,X}^{(i)}$, $E_{el,input,X}^{(i)}$, $E_{el,PV,X}^{(i)}$											
KPI's parameters to be found or estimated	$O_{C,MN,X}^{(i)}$, $FC_{k,X}^{(i)}$, $FC_{el,X}^{(i)}$, η_{boiler}, $\eta_{loss,piping}$, $c_{p,th.oil}$											
OTHER INFORMATION												
Integrated System (IS)* **IS-1:Ind.uction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**				**All**	X				
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**				**All**	X				
KPI's Calculation Responsible	CERTH											

Table 35: Operational Expenditure - OPEX (EC-KPI-03)

KPI CARD / EC-KPI-04								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**	X	**Economical**		**Social**	
KPI's Code	**EC-KPI-04**							
KPI's Name	Relative OPEX (Annual)							
KPI's Description	The annual OPEX divided by the annual quantity of product produced (t/year).							
KPI's Symbol	$O_{C,rel,X}^{(i)}$							
KPI's Units	€/t							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$O_{C,rel,X}^{(i)} = \frac{O_{C,X}^{(i)}}{APQ}$							
KPI's formula's parameters' explanation	$O_{C,X}^{(i)}$: OPEX (see EC-KPI-01) APQ: Annual produced quantity of the product - (t/year)							
KPI's parameters to be measured	APQ							
KPI's parameters to be calculated	$O_{C,X}^{(i)}$							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X		
KPI's Calculation Responsible	CERTH							

Table 36: Relative OPEX (EC-KPI-04)

KPI CARD / EC-KPI-05										
MAIN INFORMATION										
KPI's Type	**Technical**		**Environmental**		**Economical**	X	**Social**			
KPI's Code	**ECON-KPI-5**									
KPI's Name	Profit Margin (%)									
KPI's Description	Profit Margin is a key financial metric that measures the percentage of revenue that remains as profit after covering all expenses. It indicates how efficiently a company or system generates profit relative to its revenue. A higher profit margin reflects better financial performance and cost management									
KPI's Symbol	PM									
KPI's Units	%									
KPI's Determination Type	**Calculation**	X			**Measurement**					
KPI's Formula	PM= $\left(\frac{NP}{TR}\right) x\ 100$									
KPI's formula's parameters' explanation	**NP (Net Profit):** The financial gain after deducting all expenses from total revenue– (€) **TR (Total Revenue):** The total earnings from sales, services, or operations before any costs are deducted – (€)									
KPI's parameters to be measured	**TR, Total Costs**									
KPI's parameters to be calculated	**NP**									
KPI's parameters to be found or estimated	**Projected Revenue** for future periods (if required), **Estimated Cost Reductions** from efficiency improvements.									
OTHER INFORMATION										
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**				**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**				**All**	X		
KPI's Calculation Responsible	CORE									

Table 37: Profit Margin - PM (EC-KPI-05)

KPI CARD / EC-KPI-06									
MAIN INFORMATION									
KPI's Type	**Technical**		**Environmental**		**Economical**	X	**Social**		
KPI's Code	**EC-KPI-06**								
KPI's Name	Net Present Value								
KPI's Description	A metric to determine the profitability of investment. It represents the difference between the present value of cash inflows and the present value of cash outflows over a given period, considering a specific discount rate.								
KPI's Symbol	NPV								
KPI's Units	%								
KPI's Determination Type	**Calculation**	X	**Measurement**						
KPI's Formula	$\mathrm{NPV} = \sum_{i=1}^{N} \left(\frac{O_{C,B}^{(i)} - O_{C,U}^{(i)}}{(1+r)^{i}} \right) - I_{C,U}^{(0)}$								
KPI's formula's parameters' explanation	$O_{C,B}^{(i)}$: Annual OPEX of the baseline system in year i - (€/year) $O_{C,U}^{(i)}$: Annual OPEX of the upgraded system in year i - (€/year) $I_{C,U}^{(0)}$: CAPEX (see EC-KPI-01) - (€) **r**: Discount rate								
KPI's parameters to be measured	-								
KPI's parameters to be calculated	$O_{C,B}^{(i)}$, $O_{C,U}^{(i)}$, $I_{C,U}^{(0)}$								
KPI's parameters to be found or estimated	r								
OTHER INFORMATION									
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X			
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X	**All**				
KPI's Calculation Responsible	CORE								

Table 38: Net Present Value - NPV (EC-KPI-06)

KPI CARD / EC-KPI-07									
MAIN INFORMATION									
KPI's Type	**Technical**		**Environmental**		**Economical**	X	**Social**		
KPI's Code	**EC-KPI-07**								
KPI's Name	Payback Period								
KPI's Description	This KPI indicates the years of operation required for savings achieved to equal the costs incurred due to the installation and operation of the system.								
KPI's Symbol	T_P								
KPI's Units	years								
KPI's Determination Type	**Calculation**	X			**Measurement**				
KPI's Formula	$T_P = T_{I.} + t_r$ $t_r = \frac{I_{C,U}^{(0)} - \Sigma_{i=1}^{T_L}\left(O_{C,B}^{(i)} - O_{C,U}^{(i)}\right)}{O_{C,B}^{(T_L+1)} - O_{C,U}^{(T_L+1)}}$								
KPI's formula's parameters' explanation	T_L : The last period before the total costs are compensated by the accumulative operational savings - (years) t_r : The additional fraction of the year following T_L when the compensation occurs. It indicates the part of year "T_L+1" in which the accumulative operational savings become equal to upgrade costs – (years) $I_{C,U}^{(0)}$: CAPEX (see EC-KPI-01) - (€) $O_{C,B}^{(i)}$: Annual OPEX of the baseline system in year i - (€/year) $O_{C,U}^{(i)}$: Annual OPEX of the upgraded system in year i - (€/year)								
KPI's parameters to be measured	-								
KPI's parameters to be calculated	t_r , $I_{C,U}^{(0)}$, $O_{C,B}^{(i)}$, $O_{C,U}^{(i)}$								
KPI's parameters to be found or estimated	-								
OTHER INFORMATION									
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**			**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**	X		**All**			
KPI's Calculation Responsible	CERTH								

Table 39: Payback Period (EC-KPI-07)

Annex IV – Social KPIs

KPI CARD / S-KPI-01												
MAIN INFORMATION												
KPI's Type	**Technical**		**Environmental**		**Economical**		**Social**	**X**				
KPI's Code	**S-KPI-01**											
KPI's Name	Total EleCtrical Recordable Incident Rate											
KPI's Description	This KPI measures the incidence rate for electrical recordable injury and illness, as the microwave and induction heating systems can create potential hazards and risks for workers.											
KPI's Symbol	TERIR											
KPI's Units	%											
KPI's Determination Type	**Calculation**	X	**Measurement**									
KPI's Formula	$\text{TERIR} = \frac{\text{TII} * 200\,000}{\text{HWE}}$											
KPI's formula's parameters' explanation	TII: Total number of electrical injuries and illnesses. The 200 000 figures in the formula represents the number of hours 100 employees working 40 hours per week, 50 weeks per year would work, and provides the standard base for calculating incidence rates. HWE: Number of hours worked by all employees											
KPI's parameters to be measured	-											
KPI's parameters to be calculated	TII, HWE											
KPI's parameters to be found or estimated												
OTHER INFORMATION												
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X						
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X						
KPI's Calculation Responsible	ISQ											

Table 40: Total EleCtrical Recordable Incident Rate – TERIR (S-KPI-01)

KPI CARD / S-KPI-02									
MAIN INFORMATION									
KPI's Type	**Technical**		**Environmental**		**Economical**		**Social**	**X**	
KPI's Code	**S-KPI-02**								
KPI's Name	Workplace Temperature monitoring								
KPI's Description	Temperature monitoring in areas where microwave and induction heating technologies are used, ensuring a safe and comfortable working environment. This KPI measures the workplace temperatures compliance with the comfort temperature range pre-determined in facilities with microwave and induction heating equipment. Measurement Approaches: Automated temperature logging systems with strategically placed sensors; Manual temperature readings; Employee feedback on thermal comfort through regular surveys. Success Criteria: 100% compliance with temperatures in the predetermined range (e.g., 20-24°C). Consistent monitoring of workplace temperatures is crucial for ensuring worker comfort and productivity, preventing heat-related illnesses in areas with high heat generation, maintaining optimal conditions for equipment operation, identifying potential energy inefficiencies or equipment malfunctions.								
KPI's Symbol	WTM								
KPI's Units	%								
KPI's Determination Type	**Calculation**	X	**Measurement**						
KPI's Formula	$\mathrm{WTM} = \frac{\mathrm{TC}}{\mathrm{T}} * 100$								
KPI's formula's parameters' explanation	TC: Number of temperature checks performed indicating compliance with the temperature comfort range. Target areas for temperature checks: Near the microwave and induction heating equipment; Adjacent workplaces potentially affected by heat dissipation; Operators/workers stations; Storage areas having temperature-sensitive materials. T: Total of temperature verifications.								
KPI's parameters to be measured	TC								
KPI's parameters to be calculated	T								
KPI's parameters to be found or estimated	-								
OTHER INFORMATION									
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X			
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X			
KPI's Calculation Responsible	ISQ								

Table 41: Workplace Temperature monitoring – WTM (S-KPI-02)

<table>
<tr><th colspan="10">KPI CARD / S-KPI-03</th></tr>
<tr><th colspan="10">MAIN INFORMATION</th></tr>
<tr><td>KPI's Type</td><td>Technical</td><td></td><td>Environmental</td><td></td><td>Economical</td><td></td><td>Social</td><td>X</td></tr>
<tr><td>KPI's Code</td><td colspan="9">S-KPI-03</td></tr>
<tr><td>KPI's Name</td><td colspan="9">Normalized EMF Exposure Level – Induction Heating</td></tr>
<tr><td>KPI's Description</td><td colspan="9">Operators of induction furnaces and heaters are highly exposed; at 1 meter from a 1-10 kHz heating equipment, flux densities typically range from 0.03 to 0.5 mT, and may reach 5 mT at 10 cm. Similarly, devices working at a frequency of 50 Hz, may produce 5 mT fields at 20 cm, and over 0.1 mT at several meters, and the guidelines (27 μT for 3 kHz -to 10 MHz and 1 mT for 50 Hz [ICNIRP, 2010[(1)]]) are exceeded manifold during work procedures close to furnaces [SCENIHR, 2015[(2)]].
Therefore, this KPI reflects the ratio between measured magnetic flux density (B) at workstations using induction heating systems and the corresponding Exposure Limit Values (ELV) for thermal effects, as defined in Directive 2013/35/EU[(3)].
Note: Electric field strength is typically low in induction systems [ICNIRP, 2010].
Measurement Approaches: Assess the magnetic flux density (B) in μT, using isotropic field probes at operator-relevant locations, following standards such as EN 50444 or IEC 62110. Measurements must be taken in the 10–100 kHz frequency band and averaged over 6 minutes, which is in line with the Directive's requirements for thermal effects.
Success Criteria: If the KPI_{ind} is <1, the occupational exposure to EMF from induction in JOULIA project is compliant with the ELVs established by the European Directive 2013/35/EU.
Occupational reference ELVs time-varying magnetic fields – unperturbed root mean square values (ICNIRP 2010 Guidelines):
<table>
<tr><th>Frequency Range</th><th>Magnetic Flux Density (B) [T]</th></tr>
<tr><td>1 Hz – 8 Hz</td><td>$0.2/f^2$</td></tr>
<tr><td>8 Hz – 25 Hz</td><td>$0.025/f$</td></tr>
<tr><td>25 Hz – 300 Hz</td><td>1×10^{-3}</td></tr>
<tr><td>300 Hz – 3 kHz</td><td>$0.3/f$</td></tr>
<tr><td>3 kHz – 10 MHz</td><td>1×10^{-4} (i.e. 100 μT)</td></tr>
</table></td></tr>
<tr><td>KPI's Symbol</td><td colspan="9">KPI_{ind}</td></tr>
<tr><td>KPI's Units</td><td colspan="9">%</td></tr>
<tr><td>KPI's Determination Type</td><td>Calculation</td><td>X</td><td>Measurement</td><td colspan="6"></td></tr>
<tr><td>KPI's Formula</td><td colspan="9">$\mathrm{KPI_{ind}} = \frac{\mathrm{B_{measured}}}{\mathrm{B_{ELV\ directive}}}$</td></tr>
<tr><td>KPI's formula's parameters' explanation</td><td colspan="9">$\mathrm{B_{measured}}$ – Magnetic flux density in μT (measured)
$\mathrm{B_{ELV\ directive}}$ - ELV from the directive</td></tr>
<tr><td>KPI's parameters to be measured</td><td colspan="9">$\mathrm{B_{measured}}$ in μT</td></tr>
<tr><td>KPI's parameters to be calculated</td><td colspan="9">$\mathrm{KPI_{ind}}$</td></tr>
<tr><td>KPI's parameters to be found or estimated</td><td colspan="9">$\mathrm{B_{ELV\ directive}}$</td></tr>
<tr><th colspan="10">OTHER INFORMATION</th></tr>
<tr><td>Integrated System (IS)*
*IS-1: IND heating, IS-2: MW heating</td><td>IS-1</td><td>X</td><td>IS-2</td><td colspan="3"></td><td>All</td><td></td></tr>
<tr><td>KPI's correspondence (Case under evaluation)</td><td>Baseline</td><td></td><td>Upgraded</td><td colspan="3"></td><td>All</td><td>X</td></tr>
<tr><td>KPI's Calculation Responsible</td><td colspan="9">ISQ</td></tr>
</table>

Table 42: Normalized EMF Exposure Level – Induction Heating – KPIIND (S-KPI-03)

<table>
<tr><th colspan="8">KPI CARD / S-KPI-04</th></tr>
<tr><th colspan="8">MAIN INFORMATION</th></tr>
<tr><td>KPI's Type</td><td>Technical</td><td></td><td>Environmental</td><td></td><td>Economical</td><td></td><td>Social X</td></tr>
<tr><td>KPI's Code</td><td colspan="7">S-KPI-04</td></tr>
<tr><td>KPI's Name</td><td colspan="7">Normalized EMF Exposure Level – Microwave Heating (Directive 2013/35/EU)</td></tr>
<tr><td>KPI's Description</td><td colspan="7">Ratio between measured electric field strength, magnetic field strength, power density and (optionally) estimate specific energy absorption rate, in workstations using microwave heating and the corresponding Exposure Limit Value (ELV) defined in the Directive 2013/35/EU for thermal effects.
Measurement Approaches: Measure the incident electric field strength (E_{inc}-Field, volt per meter $V.m^{-1}$), incident magnetic field strength (H_{inc}-Field, ampere per meter $A.m^{-1}$), incident power density (S_{inc}, watt per square meter, $W.m^{-2}$) and, estimate specific energy absorption rate (SAR, watt per $kilogram_{body\ weight}$ $W.kg^{-1}$) near microwave equipment, for working frequencies in the range of 100 kHz - 300 GHz).
Success Criteria: If the KPI_{MW} is <1, the occupational exposure to EMF from microwave system in JOULIA project is compliant with the ELVs established by the European Directive 2013/35/EU.
Occupational ELVs (ICNIRP(1)):
<table>
<tr><th>Frequency range</th><th>Whole-body average SAR ($W.kg^{-1}$)</th><th>E_{inc}-Field ($V.m^{-1}$)</th><th>H_{inc}-Field ($A.m^{-1}$)</th><th>Sinc ($W.m^{-2}$)</th></tr>
<tr><td>0.1 – 30 MHz</td><td rowspan="5">0.4</td><td>$1504/f_M^{0.7}$</td><td>$10.8/f_M$</td><td>NA</td></tr>
<tr><td>30 – 400 MHz</td><td>139</td><td>0.36</td><td>50</td></tr>
<tr><td>0.4 – 2 GHz</td><td>$10.58f_M^{0.43}$</td><td>$0.0274/f_M^{0.43}$</td><td>$0.29/f_M^{0.86}$</td></tr>
<tr><td>2 – 6 GHz</td><td>NA</td><td>NA</td><td>200</td></tr>
<tr><td>6 – 300 GHz</td><td>NA</td><td>NA</td><td>$275/f_M^{0.177}$</td></tr>
</table></td></tr>
<tr><td>KPI's Symbol</td><td colspan="7">KPI_{MW_x}</td></tr>
<tr><td>KPI's Units</td><td colspan="7">%</td></tr>
<tr><td>KPI's Determination Type</td><td>Calculation</td><td colspan="2">X</td><td>Measurement</td><td colspan="2"></td></tr>
<tr><td>KPI's Formula</td><td colspan="7">$KPI_{MWE} = \frac{E_{inc} - Field_{measured}}{E_{inc} - Field_{ELV\ directive}}$; $KPI_{MWH} = \frac{H_{inc} - Field_{measured}}{H_{inc} - Field_{ELV\ directive}}$;
$KPI_{MWS} = \frac{S_{inc_{measured}}}{S_{inc_{ELV\ directive}}}$; $KPI_{MWSAR} = \frac{SAR_{estimated}}{SAR_{ELV\ directive}}$;</td></tr>
<tr><td>KPI's formula's parameters' explanation</td><td colspan="7">$E_{inc} - Field_{measured}$ – incident electric field strength (volt per meter $V.m^{-1}$)
$E_{inc} - Field_{ELV\ directive}$ – ELV for the incident electric field strength from ICNIRP and the Directive
$H_{inc} - Field_{measured}$ – incident magnetic field strength (ampere per meter $A.m^{-1}$)
$H_{inc} - Field_{ELV\ directive}$ – ELV for the incident magnetic field strength from ICNIRP and the Directive
$S_{inc_{measured}}$ – incident power density (S_{inc}, watt per square meter, $W.m^{-2}$)
$S_{inc_{ELV\ directive}}$ – ELV for the incident power density from ICNIRP and the Directive
$SAR_{estimated}$ – Estimated specific energy absorption rate (SAR, watt per $kilogram_{body\ weight}$ $W.kg^{-1}$)
$SAR_{ELV\ directive}$ – ELV for the whole-body average SAR from ICNIRP and the Directive</td></tr>
<tr><td>KPI's parameters to be measured</td><td colspan="7">$E_{inc} - Field$, $H_{inc} - Field$, S_{inc}</td></tr>
<tr><td>KPI's parameters to be calculated</td><td colspan="7">KPI_{MWE}, KPI_{MWH}, KPI_{MWS}</td></tr>
<tr><td>KPI's parameters to be found or estimated</td><td colspan="7">KPI_{MWSAR} for example through COMSOL Multiphysics(2)</td></tr>
<tr><th colspan="8">OTHER INFORMATION</th></tr>
<tr><td>Integrated System (IS)*
*IS-1: Induction heating system,
IS-2: Microwave heating system</td><td>IS-1</td><td></td><td>IS-2</td><td>x</td><td>All</td><td colspan="2"></td></tr>
<tr><td>KPI's correspondence (Case under evaluation)</td><td>Baseline</td><td></td><td>Upgraded</td><td></td><td>All</td><td colspan="2">X</td></tr>
<tr><td>KPI's Calculation Responsible</td><td colspan="7">ISQ</td></tr>
</table>

Table 43: Normalized EMF Exposure Level – Microwave Heating – KPIMW (S-KPI-04)

KPI CARD / S-KPI-05								
MAIN INFORMATION								
KPI's Type	**Technical**		**Environmental**		**Economical**		**Social**	**X**
KPI's Code	**S-KPI-05**							
KPI's Name	Occupational noise level compliance (ONLC)							
KPI's Description	The occupational noise level compliance aims to evaluate if the daily levels of exposure to noise and peak sound pressure to which workers are exposed during the activities of induction and microwave heating systems in JOULIA project, follow the limits established by the European Directive 2003/10/EC. This KPI is evaluated for each worker. Measurement Approaches: Monitoring of noise using a decibel meter and peak sound pressure using a sound level meter during 8h of activities of induction and microwave heating systems in JOULIA project. Success Criteria: If the ONLC is < 2 there is compliance of the daily levels of exposure to noise and peak sound pressure to which workers are exposed during the activities of induction and microwave heating systems in JOULIA project.							
KPI's Symbol	ONLC							
KPI's Units	%							
KPI's Determination Type	**Calculation**	X	**Measurement**					
KPI's Formula	$ONLC^{Wx} = \frac{L_{EX,8h}{}^{Measured}}{L_{EX,8h}{}^{Limit}} + \frac{p_{peak}{}^{Limit}}{p_{peak}{}^{Limit}}$							
KPI's formula's parameters' explanation	Wx: Identification of the worker $L_{EX,8h}{}^{Measured}$: Worker level of exposure to noise measured using a decibel meter during a 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $p_{peak}{}^{Measured}$: Peak sound pressure measured using a sound level meter during a 8h worker shift of activities of induction and microwave heating systems in JOULIA project. $L_{EX,8h}{}^{Limit}$: Daily noise exposure limit of 87 dB(A) established by the European Directive 2003/10/EC. $p_{peak}{}^{Limit}$: Peak sound pressure limit of 140 Pa established by the European Directive 2003/10/EC.							
KPI's parameters to be measured	$L_{EX,8h}{}^{Measured}$, $p_{peak}{}^{Measured}$							
KPI's parameters to be calculated	$ONLC^{Wx}$							
KPI's parameters to be found or estimated	-							
OTHER INFORMATION								
Integrated System (IS)* **IS-1: Induction heating system, IS-2: Microwave heating system*	**IS-1**		**IS-2**		**All**	X		
KPI's correspondence (Case under evaluation)	**Baseline**		**Upgraded**		**All**	X		
KPI's Calculation Responsible	ISQ							

Table 44: Occupational noise level compliance – ONLC (S-KPI-05)

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Electrification of industrial processes using induction and microwaves technologies

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