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NON-DESTRUCTIVE INSPECTION SERVICES FOR DIGITALLY ENHANCED ZERO WASTE MANUFACTURING

D2.1 Project Vision Document

V1.0

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ABBREVIATIONS / ACRONYMS

ACRONYM	MEANING
AE	Acoustics Emissions
AI	Artificial Intelligence
AMQP	Advanced Message Queuing Protocol
AR	Augmented Reality
AV	Artificial Vision
CA	Consortium Agreement
CAD	Computer-Aided Design
CBA	Cost-Benefit Analysis
CO_2	Carbon dioxide
CT	Computed Tomography
CRL	Customer Readiness Level
DT	Digital Twin
EMAT UT	Electro Magnetic Acoustic Transducer Ultrasonic Testing
EFFRA	European Factories of the Future Research Association (http://www.effra.eu/)
EFPF	European Connected Factory Platform for Agile Manufacturing (https://www.efpf.org/)
EoI	Expression-of-interests
FEM	Finite Element Model
FTR	First Time Right
F2F	Face-to-face
GA	Grant Agreement
GDPR	General Data Protection Regulation
GPU	Graphics Processing Unit
i4Q	Industrial Data Services for Quality Control in Smart Manufacturing (https://www.i4q-project.eu/)
IaaS	Inspection as a service
ICT	Information and Communication Technologies
IoT	Internet of Things
IIoT	Industrial Internet of Things
IP	Intellectual Property
IR	Infrared
IT	Information technologies
KER	Key Exploitable Result
KPI	Key Performance Indicator
LCA	Life-cycle Analysis
LCC	Life-cycle Costing
LOI	Letter of Intent
LCM	Lithography-based Ceramics Manufacturing
MQTT	Message Queuing Telemetry Transport
MinIO	https://min.io/
NDIS	Non-destructive Inspection Services
NDT	Non-destructive testing
OER	Other Exploitable Result
OPC UA	OLE for Process Control Unified Architecture
OpenCV	https://opencv.org/
PBT	Polybutylene terephthalate
PEDR	Plan for the Exploitation and Dissemination of Results
PO	Process Optimisation

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ROI	Return of Investment
RTO	Research and Technology Organisation
SME	Small and Medium Enterprise
TPE	Thermoplastic elastomers
vf-OS	Virtual Factory Operative System
ZD	Zero-defect
ZDM	Zero-defect Manufacturing
ZDMP	Zero-defect Manufacturing Platform (https://www.zdmp.eu/)
ZG3D	Zero-gravity 3D (https://www.zerogravity3d.com/)
ZW	Zero-waste
3D	Three dimensional

EXECUTIVE SUMMARY

ZDZW will develop digital non-destructive inspection services (NDIS) as a set of strategic technologies to improve production efficiency, zero-defect, and sustainable manufacturing of European industries. To pursue the main goal of reducing defects and the generated waste in manufacturing processes, ZDZW addresses defect minimisation and waste reduction in three key areas that cover the entire manufacturing process and product lifecycle: (1) Monitoring and control improvement for process quality assurance, where first-time-right (FTR) manufacturing rate can be increased, including improved durability properties and reduced waste generation; (2) digitally enhanced rework & repair procedures for necessary part recovery and scrap reduction; and (3) Continuous Sustainability evaluation to ensure the efficient use of materials and components across the full production line.

Work package WP2, and more specifically the deliverable D2.1 aims at defining a consensual project vision, establishing the state of art in terms of technologies for non-destructive quality inspection in manufacturing. Task T2.1 will provide a balanced guide document as a deliverable (D2.1), the 'Project Vision Document, which will function as a reference for the project and will be used by all partners to stay focused on the main ideas and goals of the project. The document will also be used internally to keep the performed tasks in synchronisation with the overall idea of the project. It may also be used by the partners as a source for documents, deliverables, and presentations to third parties to get an early overview of the project.

More specifically, the structure of deliverable D2.1 is presented as it follows:

- Section 1 Elevator Pitch: Executive description of the ZDZW Project and its results that explains the concept in a way such that any reader or listener can understand it in a brief period of time.
- Section 2 High Level vision: Positions the project in terms of business, research and technological objectives, and use case scenarios.
- Section 3 Positioning: Characterises the project in terms of context (business opportunities, SWOT analysis, stakeholders, post-project commercialisation) and customer needs in the areas of NDI, namely Integrity Inspection (WP4), Visual Inspection (WP5), Thermal Inspection (WP6), Integration (WP7) and Sustainability (WP8).
- Section 4 Project Results: Summarises the 11 ZDZW digitally enabled Non-Destructive Inspection Services by providing technical details addressed to end-users (industrial companies) and tech experts.
- Section 5 Milestones and Deliverables: Provides both tables with the project milestones and the project deliverables.
- Section 6 Risks: Presents the critical implementation risks and mitigation actions of the ZDZW Project.

1 ELEVATOR PITCH

ZDZW will develop digital non-destructive inspection services (NDIS) as a set of strategic technologies to improve production efficiency, zero-defect, and sustainable manufacturing of European industries. To pursue the main goal of reducing defects and the generated waste in manufacturing processes, ZDZW addresses defect minimisation and waste reduction in three key areas that cover the entire manufacturing process and product lifecycle:

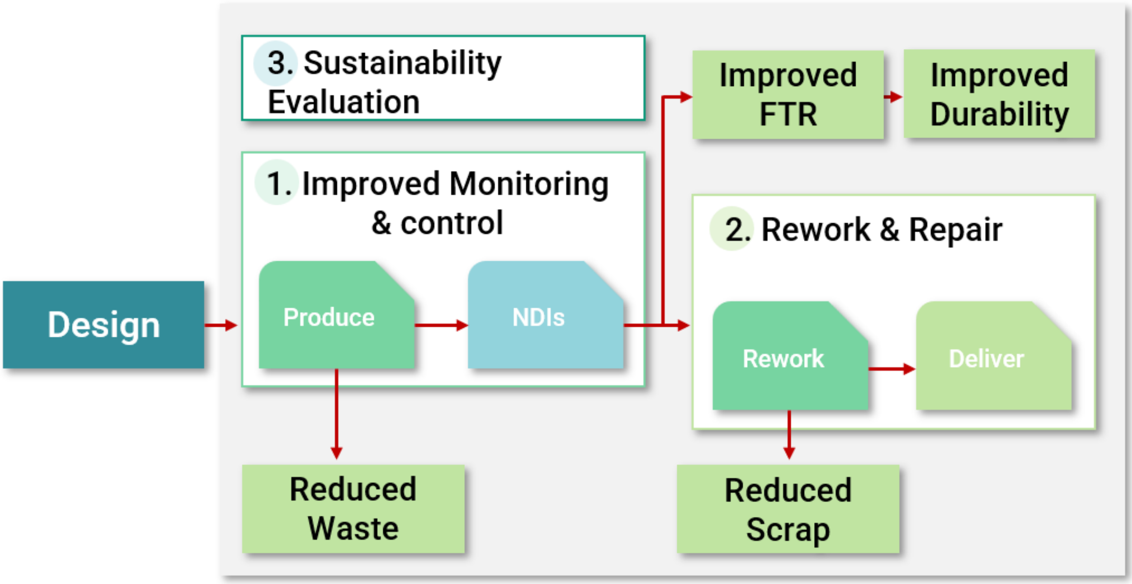

FIGURE 1. ZDZW SUSTAINABLE PRODUCTION PROCESSES

(1) Monitoring and control improvement for process quality assurance, where first time-right (FTR) manufacturing rate can be increased, including improved durability properties and reduced waste generation; (2) digitally enhanced rework & repair procedures for necessary part recovery and scrap reduction; and (3) Continuous Sustainability evaluation to ensure the efficient use of materials and components across the full production line.

To do so ZDZW will consist of the following pillars:

- ZDZW Monitoring and Control Digital Suites: ZDZW excels in offering a catalogue of non-destructive inspection (NDI) technologies, providing an accurate inline evaluation of key product parameters that have an effect in quality requirements within different technical areas, such as: Part Integrity, Visual Requirements and Thermal Process efficiency. ZDZW is committed to making the zero-defect (ZD) and zero-waste (ZW) approach accessible to different industrial sectors, production types and company size. ZDZW strongly believes in the concept of Inspection as a service (IaaS), guaranteeing its cost effectiveness and improved return of investment offering several types of subscription and pay-per-use models depending on the offered functionalities.
- ZDZW Process Monitoring and Diagnostics: IoT based NDI services developed by ZDZW are designed to inspect and diagnose 100% of produced components. The

expertise of the ZDZW consortium guarantees the successful integration of the inspection solutions in manufacturing processes whilst providing added value for industrial equipment users and support for a complete skill development of process operators and plant management. ZDZW allows the successful onsite deployment of the ZDZW Inspection Solutions. As a result, extended monitoring and diagnostics capabilities will be added to already existing production processes and machinery. The criteria to choose the six ZDZW manufacturing processes (described in Section 2.3) has been its high amount of waste produced and the world-wide spread use of these processes ensuring a global high waste reduction potential.

- ZDZW Process Control: Once extended process diagnostics capabilities offered by ZDZW, namely the Integrity Inspection, Visual Inspection and Thermal Inspection Services, have been successfully integrated in the manufacturing processes, improved ZD and ZW control capabilities can then maximize process efficiency and sustainability. As a result, ZDZW will reduce the process generated waste and maximize the number of FTR produced parts while simultaneously reducing the need of reworks and resulting scrap.

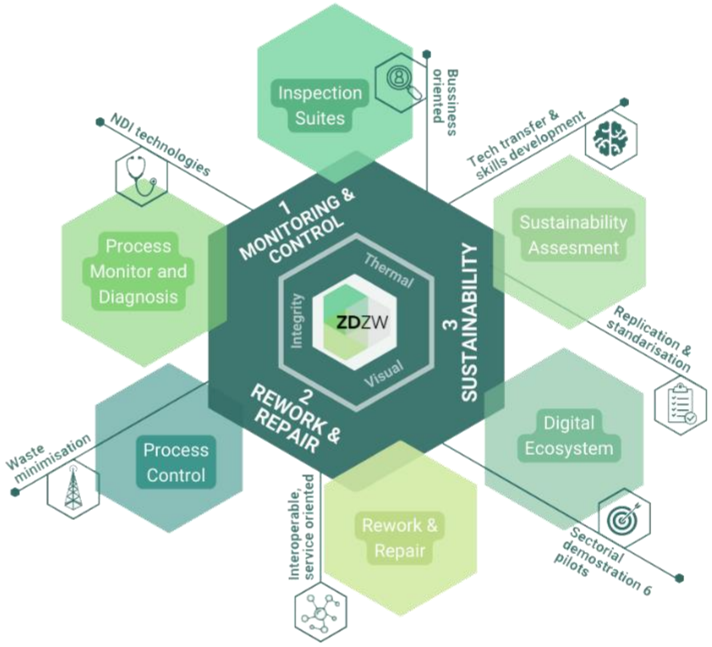

FIGURE 2. ZDZW CONCEPT

- ZDZW Rework & Repair: The diagnostics capabilities improvement will be produced by the implementation and integration of non-destructive inspection technologies in production processes and the development of algorithms for detection and decision-making as NDIS. ZDZW will deliver techniques for enhancing the reworking process of components, reducing the time spent by rework operators repairing fault components. Instead, ZDZW will guide them to defect hot spots assuring a prompt repair and avoiding its propagation trough the manufacturing process, as relevant information will be readily available in the right place.

- ZDZW Digital Ecosystem: ZDZW is strongly supported by collaboration with relevant initiatives such as ZDMP and i4Q, providing components and services that enhance important ICT aspects such as interoperability, interlinking, security, data reliability and digital platforms, whilst assuring a smooth integration with industrial systems.
- ZDZW Sustainability Assessment: ZDZW will demonstrate its ZD and ZW approach in different industrial sectors of key importance for global sustainability as it will contribute to the reduction of global plastic waste, will further develop the renewable energy sector, and will help key industrial processes to become more sustainable.

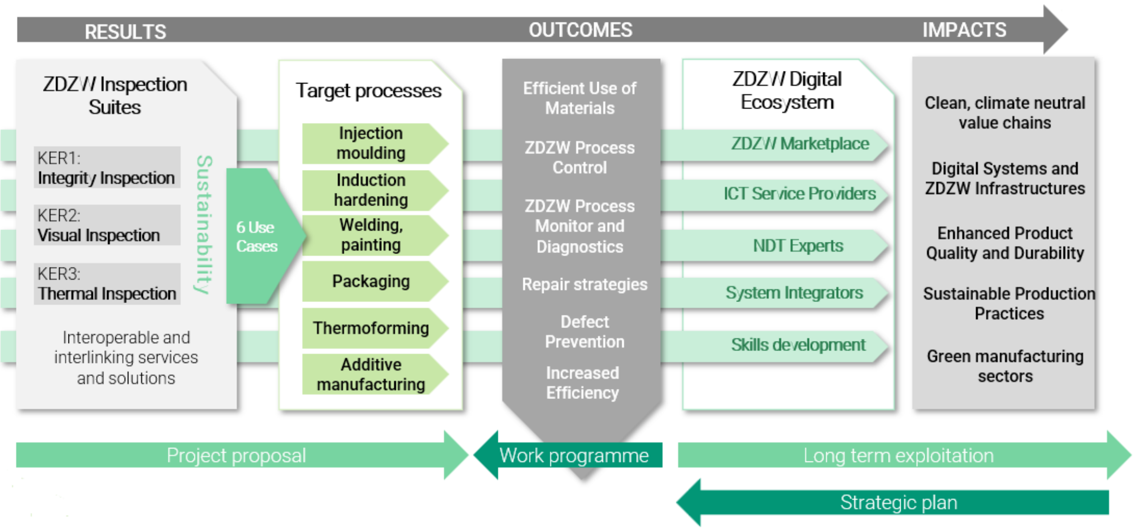

FIGURE 3. ZDZW PATHWAY TO IMPACTS

ZDZW proposes the creation of a set of digitally enabled NDI services for supporting full production lines quality assurance and process optimisation, minimizing waste and environmental impacts during the whole production process while enhancing rework procedures and increasing component life (Figure 3). As main contributions, ZDZW will create three ZDZW Inspection Suites as Key Exploitable Results, composed by a set of ZDZW Inspection Solutions with a value offer combining Equipment, Inspection Services, Documentation, Training and Consultancy Services.

The ZDZW Non-Destructive Inspection Services is a complete package consisting of 11 Solutions (Figure 4), which are described below:

- Mechanical Hardness Inspector

This solution is based on a manufacturing process digital twin that provides measurements of internal microstructural state of the part during the process and in real time. The digital twin is obtained by machine learning methods and all the data needed for the training is generated with an already validated and fast to calculate finite element simulation model of the manufacturing process. Easy to measure process variables, such as surface temperatures or machine real parameters, are also employed as inputs of the digital twin to improve the microstructural inspection quality. In this project, this solution will be implemented on an induction heat treatment manufacturing process, such as such as Warm or Hot Heading/Tempering/Induction Hardening/etc, currently employed in the metallurgy sector, although it could be implemented on any kind of manufacturing process once a validated finite element model is developed. The implementation of self-correcting algorithms in the DT will allow the induction hardening is performed in the optimum processing windows, this will assure in-line the quality of the process and, by extension, the product reliability. This type of real-time anomaly-detecting capability through the integration of NDIT, sensors, algorithms, and DT creates the opportunity to monitor the manufacturing process and reduce waste through the reduction of rejected parts.

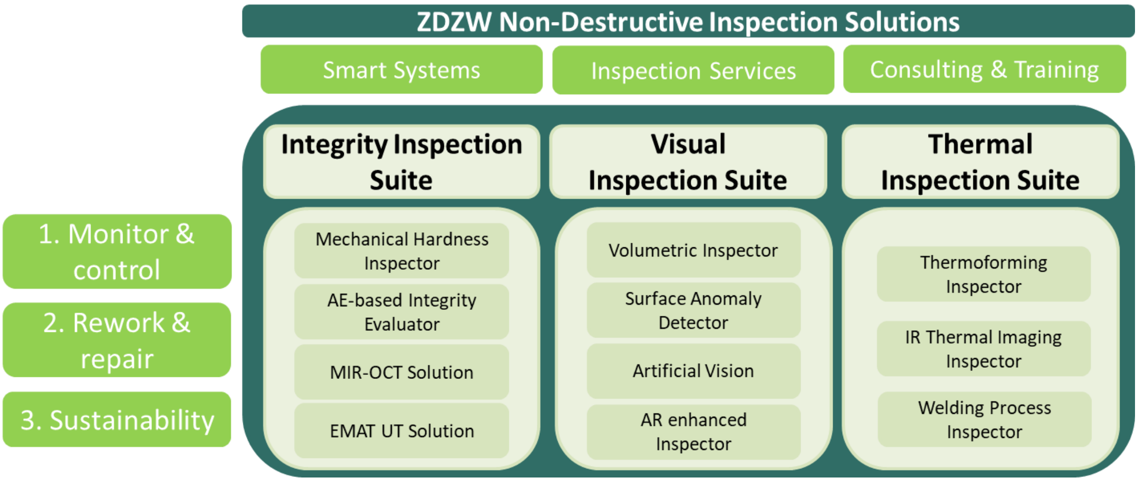

FIGURE 4. ZDZW INSPECTION SUITES FOR ZERO-WASTE MANUFACTURING

- AE-Based Integrity Evaluator

Acoustic emission (AE) applies to techniques that detect/collect sound waves generated within an inspected part. The acoustic emissions technique consists of measuring the sudden events which happen inside of the material as a response to an external load (mechanical load, thermal, corrosion, etc.). Those events show a sudden energy release, generating mechanical waves which travel across the whole component. The presence of changes in microstructure, surface and internal defects, geometric anomalies and changes, variations in surface roughness, and residual stress (due to corresponding changes in the microstructure) all affect the signature of sound moving through the part. The measurement and analysis of the acoustic events (amplitude, number of counts, amplitude energy, spectrum distribution, etc.) can give information about the internal microstructure of the component, giving an idea of its health status or other distinctive features. In this case, the crack appearance or material hardness estimation would be of great interest. The development of AI algorithms (machine such as learning methods) will improve the inline analysis and interpretation of AE signals for defect detection. AE offers the following advantages: it is non-invasive and earlier fault detection due to its higher sensitivity.

MIR-OCT Solution

Applying Fourier-domain optical coherence tomography imaging in the mid-infrared range (MIR-OCT imaging) for defect detection involves probing changes of a sample's refractive index. This is done non-destructively and without a contact medium providing a 3D volume containing microscopic sub-surface scattering information. Probing with mid-infrared light at 4 µm wavelength enables deep penetration into alumina based industrial ceramics or other type of materials in contrast to the traditionally utilized near-infrared counterpart going up to 1.5 µm wavelength. The implementation of MIR-OCT solution aimed to identify deviations during the build process caused by drifts in process parameters or random process errors, along with the detection of internal cavities and artificial flaws.

EMAT UT Solution

Electro Magnetic Acoustic Transducer is an Ultrasonic Testing (EMAT UT) technique that generates the sound in the part inspected instead of the transducer. Because the sound is generated in the part inspected instead of the transducer, EMAT is a completely non-contact technique that has significant advantages for in-service applications over more conventional piezoelectric inspection techniques. Defects, such as cracks, pits and wall loss, provide observable attenuation of the sound or phase shift due to time-of-flight change. The new EMAT UT solution will inspect the weld quality during the welding process. The inspection will be performed through EMAT sensors that inspect the weld at each pass allowing the detection of defects before adding a new pass. The development of AI algorithms (such as back propagation neural network, support vector machine, radial basis function neural network, and artificial neural networks) will be employed for real time monitoring. This solution will match manufacturing industries whose processes include multi-pass welding as a critical step, like for example the manufacture of wind turbine towers. The welded products manufacture implies the risk to generate defects during the process that affect the quality of the assets generating extra cost and waste. Nowadays it is customary to conduct quality control once the product is finished, which can lead to too long-time production and a large amount of waste.

Volumetric Inspector

Geometric dimension assessment, as part of industrial production, is a necessary activity to produce high quality items that can be assembled in a fully functional product that is free of defects. However, most quality inspection processes are still labour intensive or make use of a specific system designed for a limited geometry or design. The volumetric inspector aims to provide an in-line camera-based inspection solution capable of comparing the shape of produced goods with their intended designing, highlighting differences between them. This will prevent further integration of defective pieces in the final product, reducing total waste and energy consumption. The integration of an automatic vision system into high-volume production lines, such as plastic injection moulding or consumer goods (coffee capsules), will allow 100% inspected the parts geometry in-line production environment.

Surface Anomaly Detector

Ensuring an object free of surface defects is of utmost importance in order to obtain a final product of superior quality. However, most quality inspection processes do not cover 100% of production as they are conducted by specialized operators or make use of a specific solution designed for a limited set of defects. The surface inspector aims to provide an in-line camera-based inspection solution capable of analysing the surface of manufactured goods detecting any visual defect such as contaminations, scratches or even rugosity in finished products, highlighting zones with detected defects. This will prevent further integration of defective pieces in the final product, reducing total waste and energy consumption.

Artificial Vision

The solution is designed is designed for the manufacturing world to introduce advanced quality control and inspection systems based on machine vision integrated on an embedded platform with high computing power. The solution is based on an embedded solution integrating nVIDIA GPUs for running artificial vision and AI algorithms. Thanks to a graphical programming system, the solution easily allows the creation of image processing algorithms by experienced quality control operators who are not skilled in programming coding. The solution will allow the use of classical image processing modules and the use of modules based on AI and deep-learning algorithms. The solution also integrates IIoT communication modules for integration into enterprise automation and information systems and connection to cloud systems.

AR enhanced Inspector

When defects have been detected, they either have to be managed automatically (e.g., by a robot), or be communicated to a human being, so he or she can act on it. In the latter case, an augmented-reality-based visualization can help to locate and understand defective parts or regions. Here either screens in conjunction with cameras (video-see-through), head-mounted-displays (optical see-through) or projectors can be used as display-devices. Superimposing digital content over the real world directly is more intuitive than textual or schematic descriptions of defects and thus makes the evaluation and handling of these by humans faster and more accurate.

Thermoforming Digital Twin Solution

The goal of the thermoforming digital twin is to inspect and decrease scrap and rework during the production process of thermoformed plastic parts. Accurate detection of defective parts is required in order to enhance quality and decrease number of scraps to reduce plastic consumption. Defect detection on deep-drawn 3D parts is a challenging topic in the thermoforming processes. The DT is not an isolated digital copy; instead, it maintains two-way communication with its physical twin. It receives real-time data from the sensors monitoring (IR-cameras and pyrometers) the physical twin and, in turn, provides real-time diagnostic control commands to the physical twin. unmistakable. DTs when coupled with sensing and control equipment can mitigate defects and improve part quality through real-time closed-loop feedback control, monitor the proper functioning of critical thermoforming process parameters. This has enormous significance for the manufacturing industry. The application of AI to thermoforming technology through Digital Twins will lower costs by reducing or eliminating waste and reducing human intervention, besides creating more reliable and efficient 3D parts. In the scope of ZDZW, a non-destructive measurement technique will be developed for in-line detection of defects on manufactured 3D parts. On the other hand, the digital twin of the forming process will be obtained via FEM simulations and its calibration with real-time temperature data captured by IR cameras. The digital twin and the defect detection system will work together to determine optimum production parameters which yield non-defective products.

IR Thermal Imaging Inspector

The Infrared Thermal inspection technology can detect online and very quickly various defects such as cracks, fatigue damage, rust and delamination in dissimilar materials. Heat transfers inside the material and interacts with the existing defects. The inhomogeneous heat distribution on the surface of the part caused by the internal defects is measured using an IR camera. In the primary packaging arena for consuming goods, the heat-sealing integrity is done manually by sampling and there is no data that enables to predict and improve process failures. The arena is a blue ocean consisting of the food, beverages, vitamins, pharmaceuticals, medical devices and cosmetic. The IR Thermal Imaging Inspector enables to reveal the invisible heat-sealing process by applying inline thermal imaging combined with advanced AI algorithms. The ROI from introducing inline data, comes from preventing defected products to reach the market, reducing waste with real time trend alerts, leading to major increase in productivity, enabling to compare the performance of new sustainable materials and applying preventive maintenance.

Welding Process Inspector

A welding process must be thoroughly monitored to be fully understood. Understand your manufacturing process is the key to improve the productivity by avoiding defects and reducing any kind of waste. An online and multi-modal monitoring system contributes to the generation of digital twins by providing the real process parameters occurred during the welding process. The real manufacturing data is acquired from sensors of heterogeneous nature, enabling post-process analysis to check any deviation from the planned manufacturing process or to, e.g., compare/merge real process parameters and post-process inspection results enabling the potential generation of new knowledge. All collected data must be stored in a coherent data format facilitating its visualization, treatment, and analysis. Finally, the real-time data from the monitoring system can be processed to early warn of possible presence of defects and can be the gate to evaluate and implement new process control strategies.

- Sustainability improvement

In line with the challenge of achieving ZD and ZW manufacturing through the optimization of product quality control and monitoring in manufacturing processes, and to tackle the identified limitations of current NDI technologies (such as their high purchasing cost, and their inherent complexity for technical and digital integration and usability), the goal of ZDZW is to provide advanced cost-efficient inspection technologies, methodologies, AI defect detection algorithms, and sustainability services (database, repository, communications protocols, etc.), and sustainability services, applicable in digitally enabled sustainable manufacturing processes. This will ensure the efficient use of primary raw materials and components across the production line.

After analysing the value chain and screening the hot spots of selected manufacturing processes and sectors, the best eco-efficient processes will be evolved resulting in reduced ecological burdens and waste generation. By implementing environmental, economic, and social life cycle assessment, the complete production line will be analysed aiming at comprehensive approach to reduce waste and move forward towards a sustainable production system. The environmental assessment (LCA) will follow DIN EN ISO 14040:2006 and DIN EN ISO 14044:2006 standard norms. The economic assessment will follow Cost-Benefit Analysis (CBA) approach to claim the economic feasibility of ZDZW technology. The goal of implementing such analysis is to develop manufacturing processes that are sustainable from the very beginning of the project.

2 HIGH LEVEL VISION

The objective of ZDZW is to develop, integrate, and promote innovative, IoT-based, NDI services for process monitoring and control. ZDZW Inspection Solutions are offered in Suites covering product integrity assessment, visual and geometric properties inspection, and thermal processes monitoring and control. Proposed inspection services are designed to meet the requirements of demanding industrial processes to enhance product quality and providing a crucial reward: life-cycle extension for components with high durability requirements. The ZDZW digital ecosystem will allow continuous and real-time communication between the different monitoring and control points of the production system, and between production machines and inspection equipment. The digital ecosystem, primarily composed of non-destructive inspection technologies. The digital ecosystem will be supported by AI technologies to create comprehensive machine learning & digital twin enabled solutions that will enable product defect minimisation whilst enhancing rework procedures and maximizing process sustainability.

2.1 Objectives

The desired goal of achieving zero defects and zero waste manufacturing, through enhanced manufacturing process monitoring and quality control services, will be achieved through the following technical objectives:

O1: To reduce waste or discarded material from identified defective products or components resulting from diverse and different manufacturing full production lines and sectors and contribute to the FTR approach.

KERs: Value chain analysis and hot-spot screening on selected manufacturing sectors and processes, best eco-efficiency practices to reduce resulting environmental impact and waste generation specifically (WP8).

KPIs: Application in six manufacturing processes (WP9), >2 additional processes evaluated at the Beta Testing Camp (T9.7).

Objective and topic alignment: The project will target types of waste or discarded material from identified defective products or components that cannot be easily reworked or recycled without significant effort.

O2: To test and validate the ZDZW Inspection Solutions in six use cases, covering five different industrial sectors (automotive, home appliances, renewable energies, e-health, and food & beverages industry), manufacturing perspectives (industrial equipment manufacturers, parts and components manufacturers and final products manufacturers) and quality requirements as it is presented in Section 2.3.

KERs: Six digitally enhanced production processes in the covered industrial sectors (WP9).

KPIs: all ZDZW inspection solutions being used in the ZDZW pilots / Beta testing camp, >20 quality parameters being measured and controlled, improved metrics as defined in Section 2.3.

Objective and topic alignment: The project addresses the full production line or system, with the aim of reducing defects (e.g., rejected components or products)

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and manufacturing waste. The defect reduction and the overall quality control should be centred on such defects that reduce the yield, acceptance, or qualification of the final product, and enable a FTR production process. The system improvements address the integration of control systems and/or in-line NDI methods in demonstrative use-cases that enable for rapid feedback and/or feedforward control.

O3: To build the ZDZW Integrity Inspection Suite, to ensure manufactured products are fit for its purpose for their expected lifetime while reducing environmental impacts.

KERs: ZDZW Integrity Inspection Suite (WP4).

KPIs: Difference between classical/destructive quality metrics and new IIS based metrics <10%, error between Digital Twins' simulation and actual process behaviour <15%, >= 5 family products to be inspected, >= 10 defect detection/prediction algorithms being developed, >15 quality features to detect defects offered in the suite.

Objective and topic alignment: The application of ZDZW Integrity Inspection solutions will contribute to prevent the generation of defects and consequently increase process efficiency and sustainability. By conducting environmental, social, and economic life cycle impacts assessment of the project solutions, the project will address the full production line or system, with a comprehensive approach, with the aim of reducing defects and manufacturing waste and therefore contributing to the transition to sustainable production systems.

O4: To build the ZDZW Visual Inspection Suite that will assure an outstanding quality in terms of surface, volumetric and visual quality requirements and offer enhanced support for rework processes.

KERs: ZDZW Visual Inspection Suite (WP5).

KPIs: >= 5 family products to be inspected, >= 10 defect detection/prediction algorithms being developed, >15 features to detect defects offered in the suite.

Objective and topic alignment: The application of ZDZW Thermal Inspection Suite will contribute to prevent the generation of defects and consequently increase process efficiency and sustainability by means of geometric and surface analysis, and to enhance rework & repair processes. The ZDZW Thermal Inspection Suite will make use of large data sets and creating comprehensive machine learning algorithms for their analysis.

O5: To build the ZDZW Thermal Inspection Suite that monitors and diagnoses stability and excellence in performing thermal processes.

KERs: ZDZW Thermal Inspection Suite (WP6).

KPIs: error between Digital Twins' simulation and actual process behaviour <15%, >= 5 family products to be inspected, >= 10 defect detection/prediction algorithms being developed, >15 features to detect defects offered.

Objective and topic alignment: The application of ZDZW Thermal Inspection Suite will contribute to detect prevent the generation of defects and while reducing avoiding the usage of excess of material. The ZDZW Visual Inspection Suite will make use of large data sets and creating comprehensive machine learning algorithms for their analysis.

O6: To build and integrate key services and solutions, to assure the interoperability and interlinking of ZDZW solutions in other platforms or infrastructure elements (ZDMP, i4Q).

KERs: Interlinked ZDZW Inspection Solutions with a *Google Play* or *Apple App Store* like manufacturing sector application framework, i.e., the existing Marketplace Open Source IPR from vf-OS and ZDMP (i4FS) (WP7).

KPIs: Technical infrastructure completely functional, >75% solutions fully deployed in the ZDZW platform, monetisation services fully integrated with marketplace functionalities.

Objective and topic alignment: The integration ZDZW solutions in a cloud computing platform will ensure services interoperability and interlinking, thus, allowing large data sets stemming from all sorts of production process and material to be analysed and shared between sites.

O7: To develop Open Science practices to and share the ZDZW Project Vision and results to other stakeholders (WP2).

KERs: Project Vision, benchmarking (WP2). Contributions to standards document available (T3.6).

KPIs: Vision document and benchmarking documents available on the website (WP2), Beta Testing camp enabled with >=2 stakeholders involved (T9.7), <=2 CWAs prepared (T3.6), Datasets available per BUILD work package.

Objective and topic alignment: Research must build on existing standards or contribute to standardisation.

O8: To replicate & extend the market uptake potential (see Table 6) of the ZDZW Solutions (WP3).

KERs: Market Analysis and PEDR (T3.2), Report on End User/Customers' Validation (T3.4), Viability Plan (T3.5)

KPIs: 10 beta testers being selected from Customer Discovery Methodology (T3.4), Beta Testing camp enabled with >=2 stakeholders involved (T9.7), Advisory Group with up to 5 relevant stakeholders defined (T10.5)

Objective and topic alignment: Proposals should include a business case and exploitation strategy.

O9: To provide consultancy services including skills development, in form of dedicated webinars per inspection technology & for sustainable manufacturing approaches and training sessions to end-users. Sessions involving different social partners (i.e., process engineers, line operators) will also be addressed.

KERs: Skill development strategy, training documents available and integrated with exploitation strategy (T10.6).

KPIs: >=2 dedicated training sessions with pilot partners, >=5 info webinars organized, >100 participants involved.

Objective and topic alignment: A strategy for skills development should be presented, associating social partners when relevant.

2.2 Concepts and Models Underpinning the Project

ZDZW, from its conception, is based on existing components and solutions resulting from ZDMP and i4Q projects, which are paving the way for supporting the complete flow of industrial data, starting from data collection to data analysis, simulation, and quality prediction. This ecosystem already provides solutions that ensure data quality, security, and trustworthiness, especially tailored for manufacturing.

ZDZW aims to integrate and exploit NDI techniques with the ZDMP and i4Q platforms (Figure 5). ZDZW will primarily make use of the marketplaces as a platform to exploit generated results. ZDZW is a key part that complements this smart manufacturing ecosystem, oriented to provide smart factories with innovative monitoring, control, and predictive analysis services, based in a set of NDI solutions, excellent training and consultancy services and sustainability assessment (LCA, LCC) methodologies. These tools be evaluated and validated in the targeted use cases, with the aim of producing generic, interoperable, and modular solutions applicable, not only in the manufacturing processes targeted in the use cases, but in the wide spectrum of the manufacturing processes.

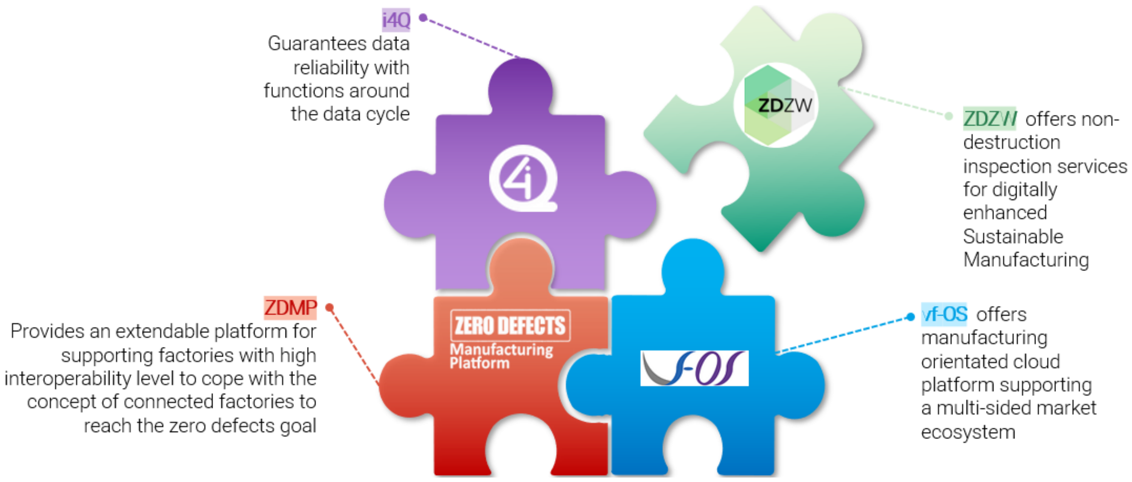

FIGURE 5: ZDZW ADDITION TO ZDM DIGITAL ECOSYSTEM

In order to achieve the objectives described in Section 2.1, ZDZW adopts a straightforward yet well-tested and effective approach (Figure 6) which includes a needs capturing part, a fundamental design phase to produce a reference architecture and framework, a build phase which delivers the actual tools and technologies used in the framework, a key evaluation phase to ensure real-world applicability of the results (see Section 2.3) and an impact generation activities centred around dissemination and exploitation actions and tasks.

FIGURE 6: ZDZW DEVELOPMENT PHASES

To conduct the project and ensure its success, the methodology will encompass the following management tools:

- Project Management: Defined, promoted, and monitored by WP1, to ensure all project activities are conducted in time and with the quality required for the success of the project.
- Industrial Scenarios Requirements Analysis: The definition of the overall high-level validation scenarios and KPIs will be developed in WP2. Pilot cases will be defined to guarantee the success of the ZDZW exploitation with new diagnostic methods for in-situ monitoring of industrial production and improved control systems, and the applicability of ZDZW Inspection Solutions to other industrial sectors beyond the ZDZW pilots. Relevant indicators and metrics, with baseline values, are stated in Section 2.3.
- Product Development: A comprehensive approach will be used for the design of the ZDZW framework. The technical specification obtained through the requirements analysis will use a hybrid approach, where the technical questionaries completed by implicated partners on each industrial partner will be employed, combining waterfall during the first project phases and agile in the development-oriented ones. During agile phases, a sprint and scrum-based approach will be taken maximizing both engagement of, and delivery to, the users.
- Demonstration: Four steps will structure demonstration in WP9: The first one will consist of collecting the requirements making the detailed definition and planning of the industrial case-studies. The second step will consist of establishing the industrial scenarios, translating the clear overview of the industrial sectors into common constraints and criteria. The third step is focused on the implementation of the specific ZDZW Solutions for each pilot. The fourth step consists of validating features and collecting feedback for improving the ZDZW Inspection Solutions.
- Dissemination and Exploitation: Dissemination (WP10) will promote the spreading of knowledge through different channels with the objective of establishing awareness and commitment from the numerous stakeholders gravitating around ZDZW. Exploitation (WP3) will be devoted to preparing an exploitation plan for the ZDZW Inspection Solutions (as a whole) ensuring that all relevant stakeholders are involved and have reached an agreement regarding IP rights.

2.3 Use Cases

ZDZW identifies the six industrial scenarios coupled with a high-level user expectation of impact across different industrial activities, sectors, and domains. These high-level generic scenarios will be explored in T2.3 fully defined as implementable pilot cases in WP9. The concrete industrial use cases introduced below will be implemented as part of

ZDZW to demonstrate the applicability and impact of the project and its results in the market under real-world conditions. It should be noted that ZDZW Inspection Solutions will be designed for any industrial sector, and not limited to the challenges of the defined pilot cases. ZDZW will deploy/validate the ZDZW Inspection Solutions in pre-defined use cases which have been chosen for their complementary nature yet building upon some common themes.

To gain a general vision of the ZDZW Pilots and see their complementarity, they have been characterised by three main criteria: (i) if the use case addresses the challenges in waste reduction, need of diagnostic methods for in-situ monitoring, improved control systems, and improved production tackled in HORIZON-CL4-2021-Twin-Transition-01-02; (ii) the set of generic technologies to be worked on, and (iii) the industrial and technical partners of the consortium that will be involved.

The following sections will describe the ZDZW Pilots. Each one includes industrial and technological partners involved, a description of the context of the quality/waste problem to be addressed, as well as the position of companies before and after the ZDZW Inspection Solutions implementation.

2.3.1 Plastic Parts Mass Production Quality Assurance

Industrial Partners: GLN / Technology providers: ITI / ZDZW Visual Inspection Suite - Monitoring

Nowadays, plastics are an indisputable presence in everyday use, but they are also synonymous with waste in the context of the environment, where there is still a significant difficulty in recycling it in its post-use. For this reason, it is imperative to look at plastics more carefully and improve your process not only downstream, but mainly upstream, to avoid excessive or unnecessary scrap production.

FIGURE 7: GLN PREMISES AT MACEIRA, LEIRIA

Different plastic parts produced by GLN PLAST, will be processed by ZDZW solutions ensuring the quality of the parts, avoiding delivery of faulty parts to the clients. Although each part presents its own challenges, all of them share similar traits and defects that can be detected using a common pipeline. Four distinct parts are considered to be analysed:

1. Protection cap: This part is part of the car's electrical system, with the function of protecting one of the battery controller's contact terminals. Due to its smaller size, visual inspection becomes more difficult, causing serious failures in the downstream quality control process, that is, in the customer's assembly lines.
2. Coffee-Capsule: Produced for the food sector, namely for a national coffee producer, for use in espresso machines in a domestic environment. For this reason, it is necessary to ensure all the quality of the capsule's composition, as it has to guarantee the quality of the coffee for at least 18 months of shelf life. On the other hand, since the part assembles with another part also produced by GLN – LID, it is necessary to ensure that the dimensions remain within the defined specifications. The coffee capsule has an extremely high production rate – around ~8,3 million pieces per week, so quality assurance can only be ensured automatically, which is currently installed in the company. In this sense, it will be necessary to find a system that can ensure 100% inspection.
3. MV Case Code: These parts are connectors that play a key role in connecting to car batteries. There are different versions of these parts. These connectors have a sealing function, so it is imperative to ensure this waterproofing, avoiding water contact with the vehicle's electrical circuit. This part is produced by 2k injection, so it contains two types of material - Polybutylene terephthalate (PBT) + Thermoplastic elastomers (TPE), which requires a more careful analysis. In this case, since it is composed by two dissimilar materials, the final destination of the scrap is the landfills.
4. Piston PSS3: This part is assembled along with other components, which together form a safety device for the car, which is responsible for cutting all the electrical circuit in case of collision. For this reason, the quality control must be taken seriously once it can compromise human safety.

All the proposed parts are processed by injection moulding manufacturing technology. These parts are either collected manually or just fall into a box and each hour an operator proceeds to sample manual inspection, based on visual aspects. Furthermore, the quality department proceeds with a sample visual inspection periodically, and they proceed additionally with dimensional inspection according to a list of points to be measured each few hours. Finally, weight control may also be performed periodically in some cases.

Before ZDZW: Regarding the visual inspection, the most common defects it can occur are related to flashes, burns, short-shots, colour contamination, deformation or fragile to touch. Depending on the type of the defects, in some cases it is still possible to rework the products, namely the defects related to flashes. The remaining defect situations leads to scrap and the post-process either could be the crushing process or to deliver to an authorized operator that will recycle the scrap material.

The defect parts either can be detected in the production line or, depending on the rejection cause, only in the quality department for the cases of sampling evaluation. Once it is detected in situ the operator warns his leader in order to decide if the production should stop to avoid the production of bad parts. However, if the defect it is only detected a few hours after, a hole batch or production quantity between sampling evaluation could be led to the rejection box. Beyond the economic impact, it is the production time that can compromise the delivery to clients, and this causes penalties to the company.

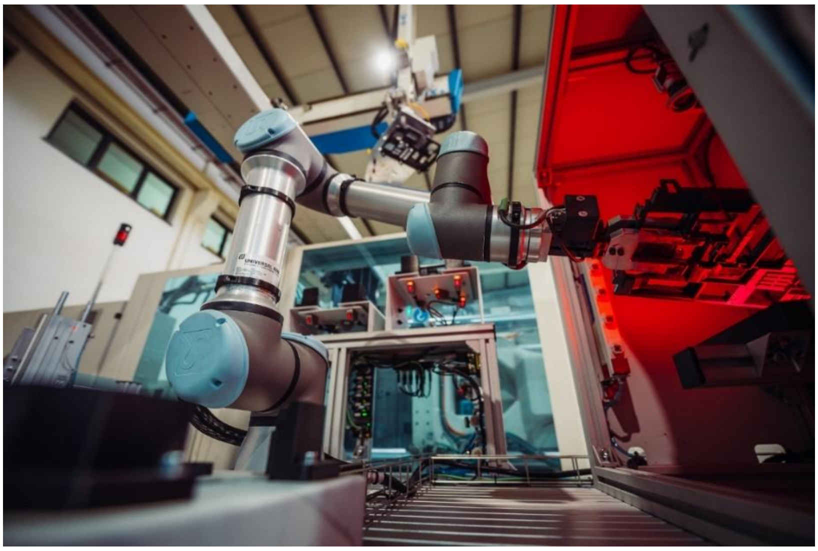

FIGURE 8: Installed Automatic Inspection for Plastic Injected Products

Since the inspection, the operator manually performs it, even if the quality department checks sample every hour or 4h, the human error it is a constant reality. In another perspective, the issues normally do not occur in constant or cyclic way, so it is quite difficult to evaluate if one batch as 100% OK parts or not. In this way, it is important to solve this issue by using and automatic inspection system (Figure 8) capable to analyse parts and separate the OK parts from the NOK, in a reliable method.

After ZDZW: Using the inspection services offered by the ZDZW Visual Inspection Suite, 100% produced parts are inspected and scrap significatively been reduced based on the accurate inspection and faults trend offered. Also, a significative improvement in the use of raw materials, based on the production management and quality inspection historical data – the access to real-data of the quality inspection and possibility to compare the production flow from the previous periods, allows the production manager to deeply analyse the trends and decide how to plan the production and deliveries. Moreover, the ZDZW approach will conduct to a new quality level, reinforcing the quality standards of the delivered products: i.e., improving clients' confidence regarding the fulfilment of the quality product specifications, and improving the confidence of the production manager regarding the outcomes of its production.

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2.3.2 Thermoplastics Forming Excellence

Industrial Partners: ARC / Technology providers: SIM, SIE / ZDZW Thermal Inspection Suite - Control

Refrigerator inner body it is the name given to the whole structure that is in the form of a bathtub when you open the refrigerator door. The inner body, which is one of the main components of the refrigerator, is produced in thermoforming lines with the new generation raw materials, namely HIPS and other chemicals. Among its properties is being opaque white, with high impact resistance, and highly resistant to acids and chemicals. This component is being produced in a thermoforming process in which the flat sheet is converted into the refrigerator inner body under heat and pressure (Figure 9). Process outputs in industrial thermoforming vary depending on raw material, mould, and ambient conditions. To manage the variability, the process is monitored with the engineering infrastructure reinforced with automation systems. Even in this situation, a 100% control of the production line cannot be achieved.

FIGURE 9: THERMOFORMING PRODUCTION LINE

Before ZDZW: ARC currently considers thermoforming results as a breakthrough product as they still offer enormous potential for quality improvement and scrap reduction. The assurance of every section of the manufactured sheet having the required thickness is not trivial. Introducing an excess of material is a non-optimized solution to assure the required quality standards, although quality and material losses cannot be avoided. Current thermoforming lines still do not offer cost-effective end-end solutions that would make possible a more sustainable production and as its upgrading into current Industry 4.0 standards is still difficult to solve. Annually, a total of 27K tons of HIPS raw materials are used in production with a current re-work rate of 5%.

After ZDZW: ARC has successfully integrated inspection services from the ZDZW Thermal Inspection Suite that bring together innovative AI-enhanced thermal imaging and processing features with advanced digital twin models that make possible a fully optimized thermoforming process, an innovation currently not present in the market. Thanks to the ZDZW Thermal Inspection Suite, thermoforming process parameters will be optimized to increase the quality and integrated in a fully automated production system. Real time process parameters will be shown in a dashboard for those responsible for the production line. ZDZW has contributed to the development of a new thermal vision system and simulation tool that can automatically measure and calculate quality relevant properties of the semi-finished product and control the final product during the production process.

Heat Transfer based Digital Twin (DT) is developed for the Thermoforming process. DT is collecting initial data from the batch of plastic sheets and performing temperature calculations on both the pre-heating and main-heating stages. Energy data received from the machine is calibrated to set the mathematical rules in the Digital Twin in such a way that the individual temperature values of each heater are tuned to reflect Radiative Heat Transfer calculations. Additional information is also available for the interior sections of the sheets which are not visible with sensor data but possible with heat transfer calculations. This information is critical to understand the formability of the thermoplastic sheets. Further, Thermal imaging is also used to improve DT predictions. Overall, the DT is guiding ARC to optimize the temperature settings as well as the cycle time.

Thermal imaging and inspection solution using AI/ML techniques will be developed for Thermoforming process to analyse the thermal images of plastic material which is used as refrigerator interior body on both the pre-heating and main-heating stages and to detect the defects such as the thinning, tearing on the thermoplastic material during heating and forming operations on the Thermoforming process. Thermal imaging, the identification of the thickness, anomaly detection and defect classification by using AI techniques on the thermoplastic sheets will increase the automation and improve the production efficiency in the Thermoforming process.

After the refrigerator body has been formed, a visual inspection will be performed, in order to detect geometric as well as surface defects. On the one hand this is done by generating an in-line 3D-scan of the finished product and comparing the result to the geometric specifications represented by the CAD-model. On the other hand, the body's surface will be inspected based on colour-camera-images, detecting surface defects like colour-deviations and scratches.

Expected Improvements: Increasing quality of the manufacturing process and decreasing the scrap ratio; increase the controllability of the manufacturing process; Successfully giving feedback to machine to optimize its parameters automatically; 2.3 M €/year saving is foreseen as a result of this project; 8% average scrap ratio that Arcelik currently has, will be decreased to 3% of scrap ratio at the end of the project (5% improvement in raw material use in the production line); efficiency of the production line is improved by 10% by reducing the downtimes with the feedback system; cycle of the production line is reduced, and the energy consumption indicators of the line are improved by 10%; quality data of the production line will be improved by 25%.

2.3.3 Wind Turbine Tower Production Enhancement

Industrial Partners: GRI / Research Partners: AIM / Technology providers: INN, VSYS, IGD / ZDZW Integrity-Visual -Thermal Inspection – Control, Rework

Wind energy represents a great commitment to the future for the diversification and sustainability of the European energy system and the fight against climate change. According to EWEA, Europe installed 14.7 GW of new wind capacity in 2020 and could install around 105GW over the next five years if the governments adopt their promised measures and aim to reach the targets set in their National Energy and Climate Change Plans. Nevertheless, wind energy industry faces big challenges such as reducing technology costs. The levelized costs of energy (LCOE) is a key indicator of global competitiveness, that in the case of offshore wind energy has a strategic goal of reducing from 10 c€/kWh in 2020 to 0.07€/kWh in 2030 through improvements across the whole value chain. Therefore, achieving higher efficiency and lower costs in the manufacturing processes of components such as metallic structures of wind turbines is essential for getting better competitiveness. In this regard, reducing defects related with the two main subprocesses of the tower manufacturing process, namely welding and painting, are the main targets the GRI pilot line due to excessive costs of repairing and/or remanufacturing defective parts.

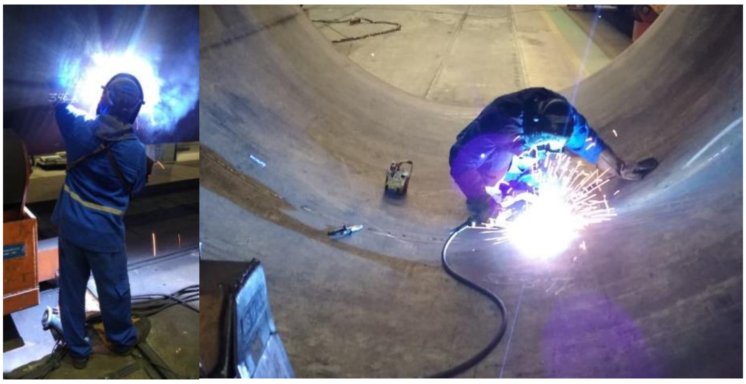

FIGURE 10: REWORKING TASKS UNDER POOR CONDITIONS FOR OPERATORS

Before ZDZW: Welding: Some of the typical defects in submerged arc welding are related with joint setup preparation as misalignments or deformations caused by thermal stress in root pass. Other important defects to be detected with inspection techniques are lack of fusion or penetration, spatters, open pores, or slag inclusions. The occurrence of a defect during welding, which remains undetected until required inspections, usually leads to a time-consuming rework stage and a situation under arduous and complex conditions for the operator to rework the affected part (Figure 10). The time needed to repair a section with a reference length of 1 m and 20 mm depth is estimated to be between 6-12 hours, costing up to 420€ per meter. With previous figures and 1% of failure rate, the costs of defects repair within the GRI capacity of four hundred towers per year can be increased up to more than 4M€. Painting: Flaking paints caused by paint problems that may appear during painting process are defects that lead to corrosion affecting in mechanical stress to the steel structure. The costs of repairing of defects which remain undetected during manufacturing process can be increased up to 15-20 times the production cost, which ranges from 15 to 20 €/m^2, reaching highest costs in least accessible offshore cases, which can cost one thousand€/m^2. Painting inspection process is manual and prone to leave undetected defects because of the absence of proper traceability and identification from the inspection to the repair stages.

After ZDZW: GRI will implement a zero-defect manufacturing strategy based on the usage of the ZDZW Integrity and Thermal Inspection Suites, which will link information of inspection techniques, which will provide quality data and defect identification with online process data. ZDZW develops a multimodal monitoring system that will feed the digital twin with real time data monitored online by sensors and thermal imaging, linking this virtual model of the welding process with the results of EMAT ultrasonic inspections. Problems that need to be fixed by hand, like painting defects, will be visualized to the worker, so he or she can easily locate the defect and document its repair, trying to increase defects detection and reduce the inspection time. Also, ZDZW approach enables data sharing and interoperability between various stages of the process by aggregating heterogeneous data to standard file formats to manage, store and process large datasets. Following this comprehensive approach, ZDZW will extract knowledge from the datasets generated allowing an early detection of defects that otherwise will propagate trough manufacturing process and will cause large and hard rework tasks for repairing the parts once the defect is identified.

Expected Improvements: 15% reduction of repairing costs for welding processes; minimisation of direct involvement of operators during welding under complex conditions (<10% of cases); improvement of automatic defect detection and feedback for real-time monitoring and welding control (>90%); 25% improvement of inspection-repair time in the painting process; guarantee the detection and repair of at least 98% of all defect's prior delivery.

2.3.4 Durable Fastening Solutions Production

Industrial Partners: ERRE / Research Partners: IKER / Technology providers: DIRA / ZDZW Integrity- Control

ERRE manufactures and markets high-quality large metric fasteners (from M30 to M64) according to technical and quality requirements of international companies. Fasteners are mostly oriented to onshore and offshore wind industry and are manufactured in large batches with demanding DNVGL[1] durability requirements (design lifetime of 20 years). Low alloy steels are employed in the manufacturing of the bolts. Wind industry is one of the contributors to the aim of the near future of reducing the carbon footprint. To this aim, the sector needs to provide products with improved mechanical properties to get more durable, lighter, and better components with less energy consumption and waste in their manufacturing stage.

To ensure the minimum normative properties for the bolts, ERRE performs heat treatment processes by means of induction hardening and tempering. Bolts are heated above their austenitization transformation temperature due to the Joule effect generated by applying an alternating current to the induction coil. Thus, the most important process parameters

1 DNVGL-ST-0361, Machinery for wind turbine, September 2016

are the frequency and the current in the coil. The heat treatment has two stages: a first fast quenching after austenitization heating to get martensitic microstructural phase and a second induction tempering process to obtain the final harness profile (Figure 11). Both processes are performed on the same automatized industrial machine. Induction heat treatments stand out for their energy efficiency, high productivity, and processing rates. On the contrary, it is a complex Multiphysics process difficult to predict and control. The features obtained at the end of the process are crucial for ensuring bolt performance and durability.

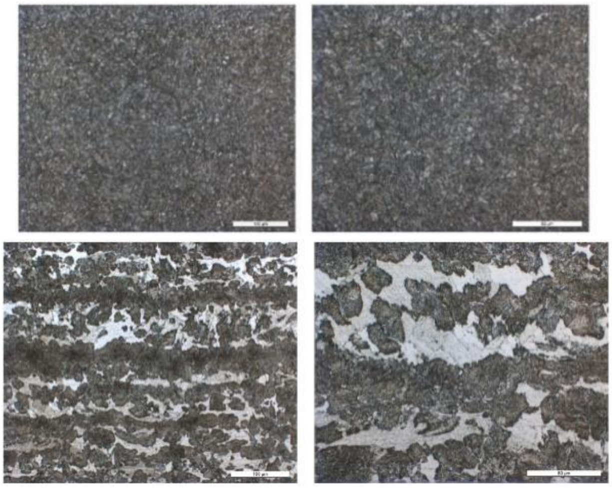

FIGURE 11: BOLT MATERIAL MICROSTRUCTURE - LEFT: CORRECTLY QUENCHED AND TEMPERED, RIGHT: NOT CORRECTLY QUENCHED AND TEMPERED FOR OPERATORS

Before ZDZW: The main requirement for the manufactured bolts is to obtain a proper microstructure (% of martensite phase) and hardness from the surface to the inner side or core of the bolt. Hence, quality control measurements are performed regularly to ensure the fulfilment of the required specifications. In addition, more measurements are done in the tunning phase of new processes and bolt geometries. All these microstructure observations and experimental measurements are performed using destructive testing such as optical microscopy and HBW hardness measurement, which reduces the productivity and generates a considerable quantity of scraps.

After ZDZW: The ZDZW Integrity Inspection Solutions will enhance the process control to excel quality requirements, reducing required destructive tests to a normative minimum. ZDZW will be implemented to monitor the induction hardening and tempering process in real-time, acting as a diagnostic method for in-situ monitoring. It is important to remark that, as an improvement of the current inspection procedure, this will also allow a traceability of each processed component. The Integrity Inspection Solution will be based on two different technologies: the finite element trained and real-time manufacturing process digital twins, and microstructure observation with acoustic emission methods. The digital twin will be developed employing machine learning methods, generating the required data with an already validated finite element simulation model. The combination of both techniques will permit the non-destructive measurement of the martensite percentage inside of the bolt and the hardness profile, while ensuring a component free of cracks, or other structural defects.

Both techniques are complementary, finite element simulation model and acoustic emission method will be jointly used to know the manufacturing quality of the bolts before to be mounted and the acoustic emission inspection will be employed to detect incipient damage during the life cycle of the bolts and to follow the evolution the potential defects precisely. Acoustic emission and anomaly detection by using AI techniques will be used for the evolution defect monitoring allows to schedule maintenance tasks at the right time and reduces risks, waste and increases the production and availability of the asset during the life cycle.

Expected Improvements: 25% reduction of energy consumption, 50% waste reduction, production improved by 33%, production costs reduced by 100 000 € annually.

2.3.5 Lithography-based eHealth Parts Production

Industrial Partners: AIR / Research Partners: UPV, DTU / Technology providers: LITH, NOR / ZDZW Integrity- Control

A fundamental change is happening in the healthcare system with a strong trend towards e-health. This entails an expected spending on digital health products and services of 12% about the total healthcare cost until 2025 and translates into a worldwide market size of 979 B€[2]. A key element for the coming e-health environment will be the in-vivo smart diagnostics and drug delivery, with a low barrier, user centric approach. One of the prerequisites for this scenario is the usability of smartphones for patient-smart application interaction, without the use of bulky and specialized communication equipment. By using a new type of proprietary ceramic-based antenna module, AIR has made the communication between smartphones and in-Vivo applications possible, allowing for significantly simplified and medical facility agnostic user interaction, on demand drug delivery as well as diagnostics. The AIR antenna module is currently being integrated into a first medical application, with an expected annual market volume of > 10M pieces. Any type of in-Vivo medical application will be possible with the AIR antenna module, ranging from endoradiosonde technology to classical implants such as pacemakers, ICDs or insulin pumps. Complexity and material quality requirements of the AIR ceramic antenna module technology demands for large volume LCM production, where in-situ process control is an absolute necessity. This is highlighted by the example of one of our ceramic antenna structures shown as in Figure 12. The size of the antenna design cannot tolerate defects as shown at the top of the middle SEM image material. The reproducibility of the antenna performance is in line with the high regulatory requirements of the sector, its zero-defect tolerance, as well as demanding documentation standards.

Before ZDZW: Electromagnetic properties of the AIR ceramic antenna module are intricately linked to the structural properties of the ceramic, however, current inspection techniques available for LCM can only be used after or between process steps. They typically involve optical (light microscopy) and rarely metrological techniques (laser scanning, CT). No online monitoring tools are available to date. Therefore, real-time operations to correct, adjust or abort the production process to eliminate detected flaws, which usually is the most critical step in terms of time and cost efficiency, are not possible.

[2] Roland Berger, "Future of health 2 / The rise of healthcare platforms" (2020).

The consequence is days of wasted machine time and scrapped parts, as ceramic electromagnetic properties are sensitive to any type of structural defect, which may lead to a significant impairment of the application signal levels. A layer-wise online inspection in lithography-based AM is therefore of significant importance for the scale-up of the AIR antenna module technology. As the ceramic electromagnetic properties are extremely sensitive to structural defects, and due to the required high structural resolution, a reworking of the ceramic components is not possible. Therefore, rejected parts typically range from 15-25 %. An improvement of the scrap rate using the current state of the art of LCM without monitoring can only be obtained with very conservative printing parameters (i.e., slow speed and longer waiting times) which limits productivity and enhances the cost per module

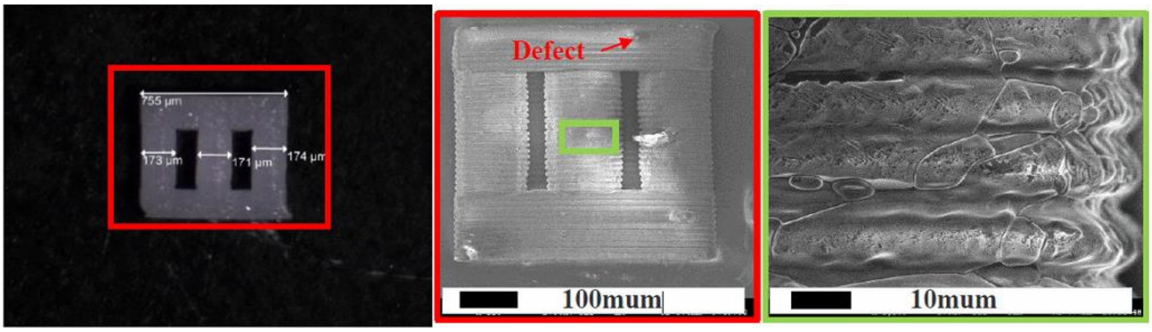

FIGURE 12: DEFECTS APPEARING IN LCM 3D PRINTING

After ZDZW: LITH has found a really cost-effective solution for bringing in-line inspection in their 3D printing machines in the ZDZW Integrity Inspection Suite, as this brings to their product three major benefits for AM methods: Defect identification: Monitoring the quality of individual parts and recognising fatal defects means that scrap parts can be identified early, and the process stopped without wasting hours or days of machine time; process optimisation: Real-time adjustment of the printing parameters such as speed, temperature, amount of material and pressure chamber temperature based on the ZDZW offered inspection parameters to maximise production; and quality control: A quality statement record for each and every component can be provided based on the recorded data. These innovations offered by LITH will make a key difference of the improvement of AIR processes to reach their production goals.

Expected Improvements: Reduction of rejected antenna modules by 50%; for an anticipated 10M antenna modules / year and ~2g per antenna module, this yield improvement translates into a waste reduction of up to 2.5 t of ceramic / year. In terms of production cost this results in savings of > 9M€ / year; a reduction in energy consumption of up to 12,5%. This will facilitate the scale up of the AIR antenna module and lead to significant savings in machine cost.

During the project AIR will lead the creation of test samples that can be used to analyse the impact of specific defects on antenna performance. This will determine which types of defects are most critical. The non-destructive integrity inspection during the manufacturing process will determine at what stage and under what circumstances these defects can occur. This allows for optimized antenna designs or printing schemes that can reduce the likelihood of defects. If the defects cannot be eliminated and it is determined during inspection that the antenna will not meet the performance requirements, the printing process can be stopped early resulting in a reduction of material waste.

2.3.6 Plastic packaging AV AI-based Quality Inspection

Industrial Partners: ILLY / Research Partners: UPV / Technology providers: VSYS / ZDZW Visual Inspection - Monitoring

The coffee pods and capsules market were valued at USD 25.07 billion in 2020, and it is projected to register a CAGR of 7.07% during the period 2021-2026. The European coffee capsule market has also witnessed an increase in demand, given that more consumers are willing to purchase coffee machines to recreate the coffee-style experience at home. A coffee capsule is a small container of plastic components (but not only that, think of the fibre filter) with a cylindrical shape, which contains a measured amount of ground coffee. Given the ratio of packaging material to consumable good, the environmental concern related to a coffee capsule packaging is remarkably high. Therefore, it is critical to increase the capacity to conduct quality control that intercepts capsule defects without generating false positives, both for better energy management and to avoid wasting raw materials such as coffee (Figure 14).

FIGURE 13: FAULTY COFFEE CAPSULES AND DEFECTED CAPSULE BAGS

Before ZDZW: Currently at ILLY, quality control on capsules takes place at the end of the production cycle, with the capsules closed and containing the coffee. Control is conducted on a sample basis using destructive tests. If a certain number of anomalies are detected in the tested capsules, the entire corresponding batch is considered unreliable and is withdrawn. As these batches consist of complete capsules with the cap sealed, reuse of materials and extraction of the contained coffee are too complex to be taken into consideration. This non-optimal quality control causes tens of thousands kg/year of capsules evaluated as non-compliant. Therefore, among the waste material, besides the plastic and non-plastic parts that form the capsule, there are also tons of coffee, which is the quality raw material whose footprint in terms of CO_2, starting from the cultivation, passing through the intercontinental transport and the industrial processing, up to the packaging, is not negligible.

After ZDZW: Making use of the ZDZW Vision Inspection Suite, it is intended to implement real-time control of the capsule forming process, monitoring the quality of individual and assembled components, before and after the coffee filling phase and after capsule closure. This will reduce the actual use of current destructive sample testing at least down to 50%, which results into a first reduction of waste, complementing it with non-destructive, continuous testing on 100% of production. The complete monitoring of the assembly of all capsules produced will also help to reduce the unsupervised elimination of batches associated with the non-conformities of the current tests, possibly limiting the rejection only to the defective capsules; moreover, it will allow to identify the defects during the various phases of capsule assembly, avoiding further unnecessary processing, thus reducing the associated amount of energy and material waste including the expensive one of the raw material, i.e. coffee.

In particular, it is planned to install an embedded vision system in the capsule body assembly machine to monitor in-line the hole punched in the septum of the bottom of the body (Figure 14); the presence, position and conformity of the hole are crucial for the correct final dispensing of coffee when using the capsule. The shape and characteristics of the hole will be correlated with the results of the destructive inspection to better define the conformity of the hole to be continuously monitored during the process: a challenging point is the productivity of the production line, which reaches 800 capsule bodies assembled per minute, which will finally be 100% monitored by the vision system once the quality control algorithm is fully defined. It could be interesting to install a vision system to monitor the drilling phase, in order to correlate it with the images of the presence, position and conformity of the hole.

FIGURE 14: DRUM WITH NEEDLES FOR PERFORATING THE CAPSULE BODIES AND PERFORATED BODIES ON THE OUTPUT LINE

In a second step of the coffee capsule assembly, a geometric vision control possibly integrated with a thermal camera will monitor in-line the sealing of the capsule lid on the capsule body once the capsule has been filled with coffee powder (Figure 15); this is also a critical control for waste reduction, as some destructive tests show that the thermal sealing of the lid may have defects that prevent proper dispensing of the liquid coffee.

In a first phase it will be possible to act on some parameters of the welders to voluntarily generate spreading capsules; in a second phase to correlate the vision and thermal system with the destructive tests.

FIGURE 15: Capsules Exiting from Lid Sealing. Multi-head Coffee Machine for Destructive Testing of Capsule Sealing

Once the capsules are fully assembled, some are packaged in vertical AL/PET bags; these bags are prepared on a specific line from the Al sheet to be cut, formed, filled with capsules and welded on several sides to be completely sealed and leak-proof. Actual immersion destructive tests should be ideally replaced with thermal monitoring of the sealing steps making use of the ZDZW Thermal Inspection Suite.

FIGURE 16: VERTICAL BAGS FORMING AND THERMO-WELDING. WATER IMMERSION TEST UNIT FOR SEALING CONTROL.

Expected Improvements: Using 100% in-line inspection at different stages of the production line, at the end of the project a significant reduction of defective parts is expected, from 0.3% of the total number of produced parts down to 0.15%, and reduction of destroyed capsules for process destructive testing, from 0.20% of the total number of produced parts down to 0.10%. This translates into a reduction in material waste by 50% and in energy consumption by about 1%.

Other improvements are expected from maintenance point of view: replacement of needles by event and not by time, for the capsules' assembly process, and an increased production line efficiency by reducing downtime for sealing problem by 33%.

3 POSITIONING

The ZDZW consortium will place a strong emphasis on turning the outcomes and technological developments of the project into value-creating products and services, as a step ahead from zero defect to integrate zero waste objectives. ZDZW will create a business plan to maximize project impacts. As well as establishing alliances between project partners, the need is foreseen to set up strategic alliances and partnerships with external stakeholders interested in the results and exploitation of ZDZW solutions, such as platform operators, software developers, manufacturing solution providers, and service providers including additional platform hosting providers. The idea of these strategic alliances is that through the collaboration scope of the ZDZW project, ZD and ZW businesses will be able to connect and create new partnerships, look for opportunities of becoming suppliers to new customers, and share business opportunities. Table 1 captures the target groups and their segments relevant to achieving and diffusing ZDZW's ambition. Understanding these profiles in the value chain is essential for the desired impact.

TABLE 1: ZDZW TARGET GROUPS AND SEGMENTS

<table>
<tr><th>Target Group</th><th colspan="2">Segments</th><th>Importance</th></tr>
<tr><td>Manufacturing Industry</td><td>Aeronautics and Space, Railway, Additive manufacturing, Consumer goods/products, Renewable Energies, Medical, Life sciences & healthcare</td><td>Construction, Manufacture of machinery and equipment, Manufacture of plastic products</td><td>HIGH</td></tr>
<tr><td colspan="4">One in ten enterprises in the EU is classified as manufacturing, the sector comprises 2M companies, is responsible for 33M jobs and is one of the European sectors that will strongly seize automatization and efficiency to reach its 2030 vision for competitiveness, productivity, and technology leadership[3]. This category encompasses the managers who design and implement industrial digital transformation strategies that integrates NDI systems to assure demanded quality requirements and breakthrough data solutions, as well as the workforce that execute the production requirements – i.e., the demand-pull perspective. The ambition of this group is to boost productivity, accomplishing efficient resource efficiency and reducing waste and scraps. ZDZW will engage with these profiles to 1) obtain first-hand requirements and feedback that will support the implementation of the project and its use cases, understanding internal processes, system integration and risk management; 2) have access to quality data acquisition; 3) raise wide-ranging awareness on the positive impact the operation of smart tools will have in real-world scenarios. Particularly relevant will be small manufacturing sites that struggle with digitalisation, defining their requirements, selecting the most appropriate technologies, planning, and initiating their strategy, and training to fill their digital skills gap. Industrial sectors and processes covered by ZDZW (WP2, WP3, WP9) will demonstrate a clear example of the potential impact for different related stakeholders. In its planned strategy, ZDZW has defined the creation of an Industrial Advisory Group (within Task 10.5 to gather and manage it) and an Open Beta Testing Camp that will used to raise awareness from project external</td></tr>
</table>

3 'MADE IN EU. The manufacturing partnership in Horizon Europe'. European Factories of the Future Research Association, Strategic Research and Innovation Agenda. Feb 2021

stakeholders. Amongst others, Gofna Liss-Rubin (NESTLÉ, Israel), Ingo Martens (HANSE-AEROSPACE, Germany), Alessandro Bassi (THINGS, Czech Rep.) and Silvia Menato (SUPSI, Switzerland), representing the food, aerospace, Digital Industry, and Sustainability sector will be involved in the Advisory group.			
Digital Tech Providers	Inspection Systems Manufacturers/Suppliers, ICT Providers, AI Engineers/ Data Scientists	Service/App Providers, Autonomous System Integrators, Standardisation Bodies	HIGH
Members who develop research outputs, innovation findings, business activities and standardisation efforts around the technologies transforming the sector –i.e., the technology-push perspective. The objective for these profiles is to investigate, advance and demonstrate the benefits offered by the NDI technologies powered by AI, distributed, and secured processing, innovative decision-making systems, and interoperable and reusable datasets. ZDZW will target active representatives in the 'Lab-To-Market' stage to support the Technology Transfer towards the 'Manufacturing Industry,' bridging the Open Innovation gap (WP3, WP4, WP5, WP6, WP7). This category includes research-driven institutions (technical universities, RTOs, spin-offs) and private-sector organisations (from highly risk-taking start-ups and SMEs to innovation units in large-scale industry). Bodies and communities driving standards (WP3) and data interoperability (WP7) will be considered as well.			
Innovation Ecosystem	EFFRA, EU DIHs / Digital Europe Programme, EIT Digital/ Manufacturing	Horizon Europe & 2020, Made In Europe, AI, Data and Robotics	MEDIUM
One of the main intentions of ZDZW is to quickly harness the knowledge and capacity of initiatives advocating for the digital and green transformation of the sector. ZDZW will leverage the participation of the consortium in active ecosystems to create synergies, extending the collaboration across the 'Manufacturing Industry' and 'Digital Tech Providers' (WP10, T10.4, T10.6). Segments will include: (i) innovation ecosystems that concentrate large communities of private-sector organisations, with a primary objective onto the European Factories of the Future Research Association (EFFRA) and those upscaling the competitiveness of SMEs; (ii) other public-funded projects under H2020/Horizon Europe driving missions in digital transformation for manufacturing; with a special focus on those from Zero-Defect Manufacturing topics and Waste reduction; and (iii) the two most relevant EU public-private research partnerships for the project, i.e. 'Made in Europe' and 'AI, Data and Robotics'.			
Policymakers	European Commission, Regulators	Member States, Local governments	MEDIUM
Group responsible for setting the rules and public incentives for a digital and green transformation of the manufacturing sector. ZDZW (WP7, WP8, WP9) will evaluate how the project results contribute to sustainable, innovative, and competitive ZD and ZW approaches for the EU, resonating with the European Green Deal.			
Society	General public	Non-specialized media	MEDIUM
ZDZW will encourage a collective understanding of the positive impact of sustainable manufacturing practices that can reduce the environmental impact of current production systems. How they will benefit the manufacturing industry, both in terms of climate change –supporting better energy and waste management, incentivising a low-carbon strategy towards the world's largest consumer of raw materials– and the labour market (WP10, T10.3).			

3.1 Key ZDZW Results towards Outcomes and Impacts

TABLE 2: ZDZW OUTCOMES AND IMPACTS

Outcomes
Demonstrate a significant increase of sustainable production through improved control systems and non-destructive inspection methods
ZDZW Inspection Solutions are designed to enhance key processes like injection moulding, thermoforming, welding, induction hardening, additive manufacturing, and assembly and packaging, where control systems play a critical role in FTR manufacturing; otherwise, defective parts from these processes typically lead to scrap because most components are difficult to reprocess. The application of ZDZW Inspection Suites will contribute to prevent the generation of defects and consequently increase process efficiency and sustainability as follows: • ZDZW Integrity Inspection Solutions (WP4): In the search for maximizing product durability to improve sustainability whilst avoiding scrap generation, ZDZW will contribute to the creation of inline integrity evaluation approaches that typically could only be evaluated by means of destructive testing. • ZDZW Visual Inspections Solutions (WP5): Intended for high serial production processes which manufacture millions of samples per year, ZDZW will develop technologies for an effective visual and geometric part quality inspection, resulting in faster detection of potential defects avoiding quality sampling with slower reaction times and resulting higher defective rates. • ZDZW Thermal Inspection Solutions (WP6): ZDZW will provide solutions for production control improvement in complex, multi-physical, highly variable processes, ensuring enhanced diagnostics and optimisation for guarantying product quality while minimizing the use of materials.
Develop methodologies & tools to prevent the generation of defects at component and system level
NDI services developed by ZDZW are designed to be used in-line, inspecting, and diagnosing 100% of produced components. As a result, extended monitoring capabilities will be added to already existing production processes and machinery in all the use cases. The developed methodologies and tools will identify different components defects at an early stage allowing the production system to prevent propagation to the system level. The digitally enhanced ZDZW approach is intended to massively exploit gathered production data and defect details to significatively reduce reworking times while maximizing the number of recovered products.
Create new diagnostic methods for in-situ monitoring of industrial production
The ZDZW Inspection Suites will introduce cost-effective inspection-as-a-service approaches for demanding applications. Adapted to different user needs, ZDZW will offer different subscription-based services for quality assurance while offering consultancy and training to maximize the value created by the project.
Ensure efficient use of materials, repair strategies, and reduced production cost and time.
The ZDZW approach targets the improvement of production processes resulting in: (i) reducing excess of material and waste generation during production; (ii) in-line quality inspection eliminating the need of destructive testing for quality assurance; (iii) process control enhancement maximizing FTR production; and (iv) enhancing rework procedures by means of a further adoption of digital technologies by industrial

operators. As a result, process efficiency, productivity and sustainability can be significatively increased.
Scientific Impact
Global leadership in clean and climate-neutral industrial value chains, circular economy and climate-neutral digital systems and infrastructures (networks, data centres), through innovative production and manufacturing processes and their digitisation, new business models, sustainable-by-design advanced materials and technologies enabling the switch to decarbonisation in all major emitting industrial sectors, including green digital technologies.
Previous projects in which ZDZW is based on, such as ZDMP and i4Q projects, are paving the way for supporting the complete flow of industrial data, starting from data collection to data analysis, simulation, and quality prediction. This ecosystem already provides solutions that ensure data quality, security, and trustworthiness, especially tailored for manufacturing. ZDZW is a key part that complements this smart manufacturing ecosystem, oriented to provide smart factories with innovative monitoring, control, and predictive analysis services, based in a set of NDI solutions and sustainability assessment (LCA, LCC) methodologies. These tools will cover a wide range of inspection techniques producing generic, interoperable, and modular solutions, not only in the targeted manufacturing processes, but in the wide spectrum of industrial processes. The aim of the consortium is to conduct a detailed business plan to exploit the solutions in the short term and to make them available to a wide range of manufacturing industries in the medium term.
Societal Impact
ZDZW will help reduce CO_2 emissions and waste in manufacturing sectors, and enhance the durability, reparability, and re-cycling of products/components.
ZDZW aims to contribute to the twin green and digital transition of the manufacturing sectors following its approach. The application of ZDZW to defined use cases has a significative impact in terms of CO_2 equivalent emission, material usage, and generated waste reduction. ZDZW enabled repair processes are intended to reduce their duration maximizing part reparability whilst pursuing an improved durability of the manufactured components.
Techno-economic Impact
Create a new green, flexible & digital way to produce goods will lead to sustainable, flexible, responsive, and resilient factories and value chains, enabled by digitisation, AI, data sharing, advanced robotics, and modularity.
ZDZW from its conception presents novel approaches for digitally enhanced ZD and ZW manufacturing. The service-oriented approach allows for modularity, cost-effectiveness, and flexibility based on Inspection being offered as a Service (IaaS), adaptable to different industrial sectors, production types and company sizes. This approach aims to guarantee interoperability with legacy systems existing in the industrial environments, and full data traceability, offering an excellent quality of service.

3.2 Requirements and Potential Barriers

ZDZW has studied potential barriers to achieve the expected impacts. Nevertheless, the consortium will strive to use the identified barriers as enablers to unleash its innovation potential:

- Regulation: ZDZW will accurately consider various requirements set by different national, European, and international laws (e.g., GDPR, 2021/0106 COM (2021) for AI, HACCP for food packaging products; IATF 16949 for automotive sectors). These requirements may impose constraints on how the protection, monitoring, and management of the infrastructure, data and quality requirements are managed by ZDZW to ensure legal compliance.
- Standards: To drive quick and widespread adoption of the ZDZW Inspection Solutions, coherence with standards may pose limitations on how the solutions can be realised and used. ZDZW will thus take into consideration existing relevant standards (ISO 9001 Quality; ISO 14001 Environment; ISO 50001 Energy; EMAS; B-Corp; ISO 14064-1 GHG; ISO 27001 Information Security; ISO 45001 Occupational H&S; 6-Sigma & Advanced Analytics Techniques; ISO 14040/14044 (LCA), ISO 14067 (Carbon Footprint), ILCD handbook, GHG reporting standard, PEF guidelines; Total Productive Maintenance (TPM)) and align the developments with them early in the project.
- Technical barriers: The development of the ZDZW Inspection Solutions and its deployment is partially dependent on legacy systems and technologies dictated by the pertinent operating environments of machinery manufacturing companies. Guaranteeing interoperability with legacy technologies while enabling the full benefits of the newly developed solutions may pose challenges or constraints on the technical solutions employed.
- Workforce considerations: ZDZW has relevant expertise and experience to develop the ZDZW Inspection Solutions and to further use and commercialize them. However, ZDZW will continuously work towards raising awareness, training individuals, disseminating results, and growing the networks and improving skills of quality management professionals.
- Public acceptance: ZD and ZW technologies are confronted with several barriers to their wide uptake. Users often do not have the knowledge or skills to follow the rapid technological advancements and consequently lose their trust in them. To this end, ZDZW will consider end users' needs, market trends, and existing standards to deliver solutions that will facilitate higher implementation of sustainable manufacturing approaches.
- Sustainability: Some impacts of the project will materialize only after its successful completion as third-party players start utilizing the developed ZDZW Inspection Solutions. To support the adoption of the developed technologies, active involvement of relevant project partners may be required.

3.3 Scale and Significance of ZDZW's contribution

Table 3 summarises the impacts of the ZDZW Inspection Solutions implementation. The quantified values, based on the expected impacts of the industrial partners, can be extrapolated to any industrial sector with similar processes:

Funded by the European Union

TABLE 3: GLOBAL SCALE IMPACTS OF ZDZW

	Production	Sustainability	Business
Injection Moulding: Global plastic market size is expected to reach EUR 632.3 billion by 2028. It is expected to expand at a CAGR of 3.4% from 2021 to 2028.			
Significance	Three percent reduction of the rejection rates	Nine percent - 12% Energy consumption reduction; 4 – 6% waste reduction; 2-3% less waste forward to landfills	3-5% of the global savings of the core business
Thermoforming: Global thermoform packaging market size was valued at EUR 36.60 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 5.2% from 2021 to 2028.			
Significance	Five percent reduction of the scrap	Five percent reduction of raw material use Ten percent Energy consumption reduction	85 000 €/(year tonne) savings
Welding (Wind energy): Renewable energy represented ~20% of energy consumed in the EU-27			
Significance	>90% of total defects being detected by real-time monitoring and welding control; 25% improvement of inspection-repair time in the painting process	Fifteen percent reduction of repairing costs for welding processes; minimisation of direct involvement of operators during welding under complex conditions (<10% of cases)	Guarantee the detection and repair of at least 98% of all defects prior to delivery
Induction hardening (Wind energy): Renewable energy represented ~20% of energy consumed in the EU-27			
Significance	Three percent reduction of the rejection rates	Fifty percent waste reduction Twenty-five percent energy consumption reduction	Thirty-three percent production improvement
Additive manufacturing: Global 3D printing market[4] in 2020 was estimated at $12.6bn on average, ranging from $8.4bn to $16.6bn.			
Significance	Reduction of rejected antenna modules by 50%;	For an anticipated 10M antenna modules / year and ~2g per antenna module, this yield improvement translates into a waste reduction of up to 2.5 t of ceramic / year. A reduction in energy consumption of up to 12.5%.	Savings of > 9M€ p.a. production costs. This will facilitate the scale up of the AIR antenna module and lead to significant machine cost savings.

[4] Additive manufacturing trend report 2021. Tess Roberts (Hubs B.V.). www.hubs.com

Packaging and Assembling: Revenue in the Food market amounts to US$8,049,240m in 2021. The market is expected to grow annually by 3.14% (CAGR 2021-2025).			
Significance	One percent reduction of defects	Reduction of 10 t per year of generated waste; 1% reduction of energy consumption.	Ten percent production improvement

3.4 ZDZW Exploitation

A preliminary approach to the Plan for the Exploitation and Dissemination of Results (D3.2) is described considering a tailor-made methodology based on the Customer Discovery Loop. It aims to evaluate the project's results by validating its (1) Desirability (Solving Customer-related uncertainty); (2) Feasibility (Testing available technology and resources, activities, and partners); and (3) Viability (Financial opportunity assessment). The result of this task is to achieve a (4) Validated Business Model that allows partners to position themselves with a clear go-to-market plan. This methodology aims at increasing the Customer Readiness Levels[5] (CRLs) of the Key Exploitable Results (KERs).

The key element in this process is the application of the Customer Discovery Methodology which consist of evaluating the previously prioritized KERs with potential early adopters/end users through EoIs call targeted at relevant FBOX Community followed by 'focus group' and 'customer interviews' and resulting in "Willingness to pay"[6] as a central part in the methodology. Two interactions with end-users are foreseen, the first one based on the controlled environment of the FBOX community, and the second, aiming a pre-validated hypothesis at the broader public using simple landing-page campaigns. To align the process with consortium business strategy, another loop will be aiming at the "willingness to sell" study that should confirm the viability of the exploitation scenarios from its owners' point of view. Following the Customer Readiness Levels (CRL) scale, the innovation process becomes more customer-driven, and increases the success rate of technology adoption. During the project, the CLR will be raised from the Level 1 (hypothesizing on needs in the market) to Level 7 (customers in extended product testing) rolling out the real market introduction phase during the sustainability period of the project.

3.4.1 Identification and Analysis of the Key Exploitable Results

Overall Exploitation (what new knowledge the project will generate?): The following table shows the KERs to be exploited jointly, during and beyond the project, to maximize ZDZW results, detailing: Developed by (Who will work on the implementation of the KER); Exploitation by (Who is interested in commercializing the results?); Targeted Industry (To who the KER is aimed at?).

5 Customer Readiness Levels is a part of The KTH Innovation Readiness Level™ Model is developed by KTH Innovation.
6 Felix OBERHOLZER-GEE, Better, Simpler Strategy: A Value-Based Guide to Exceptional Performance

TABLE 4: JOINT EXPLOITATION KERS

KERs	Developed by	Commercialized by	Targeted Industries
KER 1 Integrity Inspection Suite	IKER, DIRA, NOR, UPV, INN, AIM	i4FS, IKER, DIRA, NOR, INN	Renewable energy, Aeronautics and Space, Railway, Additive manuf., Construction, Consumer goods/products, Medical
KER 2 Visual Inspection Suite	ITI, UPV, VSYS, IGD	i4FS, ITI, VSYS	Manufacturer (any), Aeronautics and Space, Agriculture and food, Construction, Consumer goods/products, Life sciences
KER 3 Thermal Inspection Suite	SIEMENS, AIM, YOR, SIM	i4FS, SIM, YOR, SIE	Consumer goods/products, Manufacture of machinery and equipment, Manufacture of rubber and plastic products, Professional, Scientific and Technical Activities, ICT

Exploitation Strategy (where and how?): Table 5 summarizes the Plan for the Exploitation of Results for each KER describing, in a concrete and comprehensive way, the full range of potential uses (What kind of problem the proposed solution will solve?) and **users** (Who will use these results?), the appropriate channels of interaction with potential users (How will end-users be involved with the generated results?) and possible **metrics** of our results (KPIs to measure the benefits that will be delivered). T3.3 will deploy the exploitation strategy:

TABLE 5: ZDZW EXPLOITATION – USERS, CHANNELS, BENEFITS

Main Uses (What)	Target Users (Who)	Channels (How)	Benefits (KPIs)
KER 1 - Integrity Inspection Suite			
To develop NDI solutions dealing with quality parameters that estimate the durability/integrity of an inspected parameter	Component manufacturers where durability is a key parameter, production processes for mechanical properties enhancement	Demos/pilots, marketing (fairs, events, promotions), prescribers' network, Certifiers/ Regulation entities, marketing materials, service selling, F2F meetings, SW services for digitalization of industry	Integrity inspection parameters obtained from NDI vs Destructive testing, Speed of the evaluation, Cost
KER 2 - Visual Inspection Suite			
To detect production defects in a manufacturing line by getting info about the shape and texture of a real-world object.	Integrators, interested in incorporating visual inspection solutions in their product/services End users as clients and direct users	Demos/pilots, marketing (fairs, events, promotions), prescribers' network, Certifiers/ Regulation entities, marketing materials, service selling, F2F meetings, Software services/solutions for digitalization	Defects detection precision. 100% production inspection and complex defects detection.
KER 3 - Thermal Inspection Suite			
To monitor and control complex production processes where heat transfer is a key aspect	Industrial partners, production facilities applying heat treatment in their manufacturing processes	Demos, marketing (fairs, events), prescribers' network, Regulation entities, marketing materials, service selling, F2F meetings, SW services for industry digitalization	Accuracy precision of AI, the image recognition model for thermal cameras

3.4.2 Joint Exploitation Strategy

ZDZW Exploitation activities (WP3) will help partners understand what they are "in for" and mitigate the risk for the partners that will exploit the project after the end of EU funding.

The main idea of the proposed technology transfer methodology is to facilitate connections and understand end-users' needs before launching the last version of the envisaged ZDZW products and services. For that reason, a Customer Discovery Methodology[7] will be applied and incorporated in the process of definition and validation of ZDZW joint exploitation strategy and business model. The progress of this task will be measured via the CRLs[3] scale. Taking as a starting point the preliminary Business Model (CRL 1), assembled thanks to feedback gathered during the proposal phase from both partners of the consortium and potential customers, ZDZW will settle a product-market fit, meaning to find a product that would find a customer segment and generate profit. To explore what this product-market fit can be, it is crucial to evaluate the main hypothesis of the Business Canvas by a process of ideation and testing loop (lean approach). The process includes following stages to evaluate hypotheses:

1. KER Definition Workshop (CRL 1) to explore interrelations between KERs and partners involvement.
2. Acceleration Program (CRL 2) divided in three workshop modules: Value Proposition Canvas, Buyer Persona Canvas, Business Model Canvas.
3. KERs Hypothesis Validation (CRL 3-4) by selecting early adopters through EoIs and gathering the LoIs.
4. KER Pre-validated hypothesis (CRL 5) via "Willingness to pay" assessment by interviews or focus group and "Willingness to sell" estimations by monitoring Return on Investment (ROI).
5. Stakeholder Out-Reach (CRL 6) by testing Minimum Valuable Product value via Landing-page campaign.
6. Go-to-Market Guidelines (CRL 7) insights extracted through first mock-up and MVP validation.

The strength of the lean methodology resides in the possibility of evaluating the exploitation strategy during the project. The consortium will be able to choose the adequate entity supported by partners who will bring the ZDZW products to the market. Following various iterations of the ideation and testing loop, a Business Model is validated via Value creation Opportunity mapping. A dashboard will allow a review on all the process and extract main KPIs, IP issues and financial simulation. A last review with the consortium is done giving a chance to each partner with interest in exploiting the project's results to position itself towards the final solution with a clear status (paying member, client...). Overall, the proposed methodology helps to significantly shorten the time to market and accelerate the innovation process, therefore reducing the overall cost of bringing the ZDZW Inspection Solutions on the market.

3.4.3 Individual Exploitation Efforts

Individual exploitation efforts, distinctive components/subsystems of the KERs with potential to be commercialised as stand-alone components for other applications, have

[7] Customer Discovery methodology stems from the Lean Start-up Methodology which is suitable developing businesses and products, which aims to shorten product development cycles and rapidly discover if a proposed business model is viable; this is achieved by adopting a combination of business-hypothesis-driven experimentation, iterative product releases, and validated learning. The methodology was brought to life in 2008 by Eric Ries.

also been considered following the initial survey sent to all partners of the consortium during the proposal phase. The exploitation strategy, business opportunities and type of protection have been already identified for the OERs, which are the ZDZW Inspection Solutions.

- Exploitation Strategy: IaaS (inspection-as-a-service) (3 inspections suites), Sale/rental/licensing/pay-per-use of inspection systems and software solutions. Business Opportunities: Consultancy, service, licensing, smart contracting through marketplaces. Type of Protection: Patent, utility model, copyright, and scientific publications.

3.4.4 Business Plan

ZDZW starting point is the initial business model defined at proposal's stage, which will be reviewed, updated, and validated during the project's execution following a lean approach.

- The Business Model describes how the KERs are positioned within its value chain, and how it organizes its relations with its suppliers, clients, and partners to generate profits. In Section 3.4.4 an outline of the Business Models (based on Lean Canvas approach) is defined, being the Business Plan defined during the project. This information will evolve into a suitable high-level business plan depicting the exploitation strategy, which will also feed the final PEDR.
- Lean Canvas: At this stage, a first Lean Canvas for each KER has been assembled thanks to feedback gathered during the proposal phase from both partners of the consortium and potential customers.
- Hypothesis on the most adequate Exploitation Strategy: The foreseen joint exploitation strategy by the consortium is the uptake the ZDZW Inspection Solutions and will bring it to the market. The presented strategy is based on answers from a survey that was gathered from all participating project partners, specifically focusing on the owners of the KERs and core IP.
- Main integrated KERs: The Lean Canvas will evolve into one single business model encompassing all KERs. The joint exploitation strategy focuses on exploiting the main integrated KER and will be linked to related marketplaces. Regarding the exploitation of the individual KERs from the ZDZW Inspection Suites, the interested partners will participate for the individual exploitation strategies.
- Market Opportunity: Apart from the specific market share of the pilot sectors (see Table 3), the global demand for NDI methods follows specially the market trend from Manufacturing (counting for 2M companies and about 15% EU's GPD). The implementation of ZDZW Inspection Solutions in industry will be set by the evolution of NDI systems and digitalization, especially for SMEs, for Production Processes. The digital transformation in manufacturing market worldwide was valued (2020) at USD 264 billion, with a CAGR of 19% over 2021-26 (also for EU), and for example, related with ZDZW techniques, the machine condition monitoring

market will grow at 9.4% CAGR[8], On other side, NDI market showed an expected growth at a 6.7% CAGR in 2021-28 in 2020, affected by Covid-19, but switching to the rise from technological innovations and being the biggest accelerator of digitalisation in manufacturing[9]. From these elements, the penetration of NDI is expected to improve in next years. The ZDZW Inspection Suites, will benefit from these growing markets and adding value to existing manufacturing processes. Other elements that will facilitate the uptake of these innovative technologies from NDI range from the cost of equipment, lack of skilled workforce and stringent regulations for work safety.

The initial forecast for the KERs business at short – medium period has been estimated by the corresponding partners, based on their current activities, and considering an increase due to the benefits or the project.

TABLE 6: EXPECTED MARKET IMPACT OF ZDZW SOLUTIONS

Partner	ZDZW KER	Related business opportunities	Potential Market	Expected market (3-4 years after ZDZW)
IKER	KER 1	Mechanical Hardness Inspector	Global material testing[10]: ~880M€ Induction machine 8000 machines/y	10% - 3200 machines
IKER	KER 1	AE-based Integrity Evaluator	Global: ~111M€ by 2027 Integrity inspection, pred. maintenance	AE: 25-75units/years considering Spain/LATAM markets
NOR	KER 1	MIR-OCT Solution	MIR:SC sources ~60 M€, MIR share ~2 M€ in 2020. 10M€ in 2028 Global OCT: >1 B€, Industry 4.0 10M€	MIR: 50% (3 M€/y) OCT: 50% (40-50 scanners; 5M€/y)
INN	KER 1	EMAT UT solution	Global arc welding equipment 5.7 B$ by 2026	New tool introduction by collaborations with the main EU and US manufacturers.
ITI	KER 2	Volumetric Inspector	Quality assurance segment is projected to expand CAGR of 14.4% from 2020 to 2027.	40-60 units (6 - 10 M€) (considering market size of 3.46billion USD by 2027)
ITI	KER 2	Surface Anomaly Detector	Quality assurance segment is projected to expand CAGR of 14.4% from 2020 to 2027.	40-60 units (6 - 10 M€) (considering market size of 3.46billion USD by 2027)

[8] Digital Transformation Market in Manufacturing – Growth, Trends, Covid-10 Impact – Mordor Intelligence 2020 & EU Digital transformation Market from Marqual IT Solutions.
[9] NDT Market Size, Share & Trends Analysis report – Market Analysis Report, 2021.
[10] Global Material Testing Market Size By Product (Universal Testing Machines, Servohydraulic Testing Machines, Hardness Testing Equipment), By End User (Automotive, Construction, Educational Institutions, Aerospace & Defense), By Geographic Scope And Forecast. Report ID: 75193. https://www.verifiedmarketresearch.com/product/material-testing-market/

Partner	ZDZW KER	Related business opportunities	Potential Market	Expected market (3-4 years after ZDZW)
			Market size value in 2020: USD 1.32b	
VSYS	KER 2	Artificial Vision	Small formfactor assembled elements product	Embedded machine vision devices and AV/AI software 2M€/y
IGD	KER 2	AR-enhanced Inspector	Global mechanical engineering: ~649 B€ in 2020 German automotive: ~378B€ in 2020	AR-quality-control standard in engineering and automotive industry
SIM	KER 3	Heat Transfer Digital Twin	Global Refrigeration Sector 2000 Thermoforming Machines.	Thirty percent (SaaS10k€/unit: 6M€/y)
YOR	KER 3	IR Thermal Imaging	Food and pharma over five thousand lines in the US and Europe	3%-5% (200 systems) 4 B bottles/y
AIM	KER 3	Welding Process Monitoring	WT manufacturers, global demand: 65.9GW, CAGR (2020-2027): 5.2%[11] Welding equipment OEMs, 9.9 B$ in 2019, CAGR (2021-2024): 4.8%[12]	10 units/y (1.2 M€)
i4FS	All	Industry 4.0 Solutions for developers & manufacturers	Cumulative Marketplace users	Cumulative ZDZW market

A Business Model Canvas (Figure 17) has been prepared as the starting point for the project' business model to describe how the KERs are positioned within its value chain, and relations with customers, infrastructure, etc. to generate profits.

[11] Grand View Research (2020). Wind Power Market Size, Share & Trends Analysis Report.
[12] WBOC (2021). Welding Equipment Market Size In 2021.

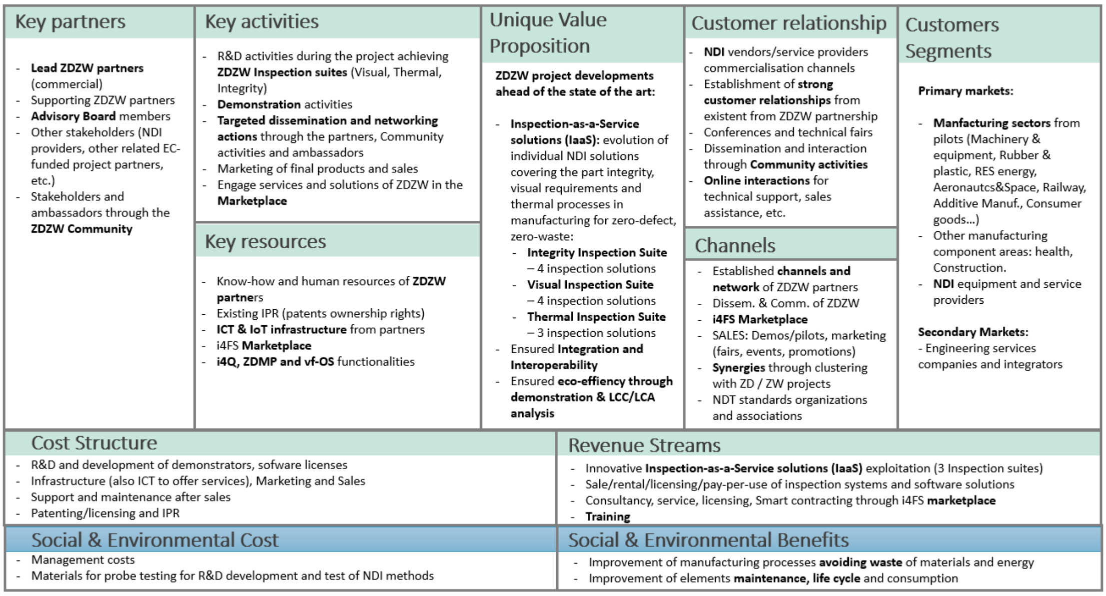

FIGURE 17: ZDZW BUSINESS MODEL CANVAS

4 PROJECT RESULTS

4.1 ZDZW Architecture

ZDZW makes uses of existing results from projects such as ZDMP and i4Q, which will serve as a basis for the development of the ZDZW Inspection Solutions. Figure 18 presents the high-level architecture that will make use of existing components and apps from ZDMP and i4Q.

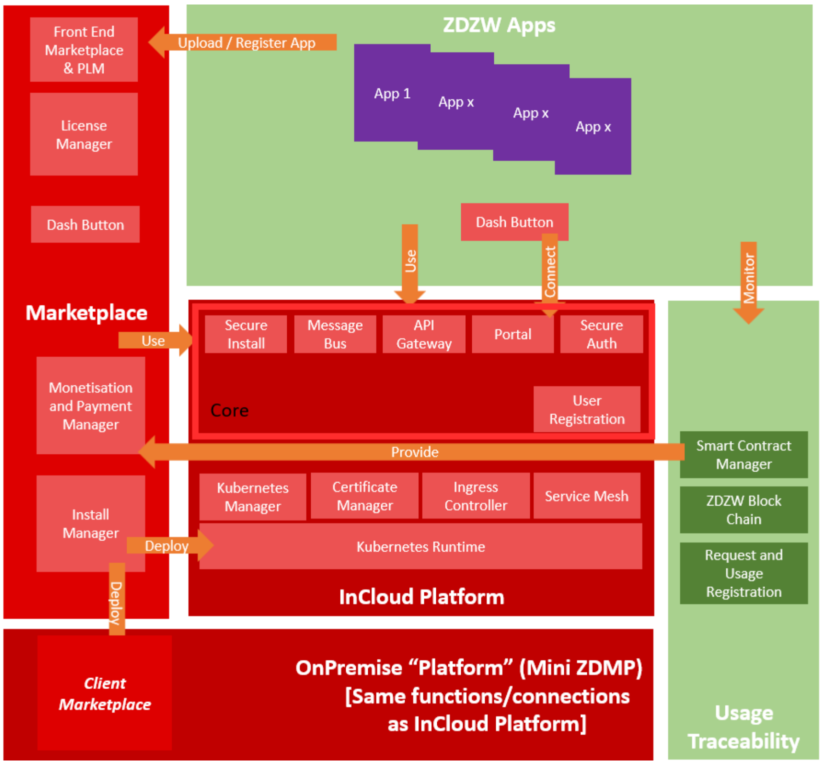

FIGURE 18: ZDZW HIGH LEVEL ARCHITECTURE.

4.2 Technological Readiness Level

ZDZW considers that technology beneficiaries will be able to fine-tune and enhance their own / existing products and services, reusing and repurposing solid background and commercial grade-products reaching during the project duration a "system prototype demonstration in operational environment" (TRL 7) for the full ZDZW Inspection Suites, as Table 7 addresses. To this end, the exploitation methodology of Customer Discovery Loop will build the path for ensuring the results' business readiness. From the identification of the Suites as Key Exploitable Results and defining their business models and market analysis, this methodology (Section 3.4 / T3.1 and T3.4) will put in contact possible customers with technical partners, for a collaborative interaction in which the needs from customers (market reach) would be put into value and considered for the technical solutions, ensuring their maturity from research to reach the market path (customer readiness level). Beyond any RTD enhancements of WP4-6 technologies, one critical set of mandatory enhancements for them all are to be compatible with the Interoperability and integration requirements and features of WP7.

TABLE 7: ZDZW PROJECT KERS START AND END TRL

ZDZW	ZDZW Inspection Solutions	WP	Current Technologies	Start TRL	End TRL
Integrity Inspection Suite	Mechanical Hardness Inspector	4	Pyrometers, Thermocouples, Current probes, Voltage probes, Power probes, FEA modelling-Ansys, pyMOR-Reduced Order Modelling, Keras-Recurrent Neural Networks, i4Q DT Simulation Services	5	7
	AE-based Integrity Evaluator	4	AE piezoelectric sensors, Preamplifiers, Multi-channel data acquisition system, Magnetic yoke, Vallen AE-Suite, ZDMP PO Runtime	5-6	7-8
	MIR-OCT Solution	4	mid-IR supercontinuum laser, Pixel-wise defect segmentation, convolutional networks Tensorflow, OpenCV, ZDMP PO Runtime	5	7-8
	EMAT UT solution	4	System for the inspection of multi-pass welds	5	7-8
Visual Inspection Suite	Volumetric Inspector	5	ZG3D - Multi-camera scanning systems, Tensorflow, Statistical shape model, Slicer - Elastic alignment.	5	7
	Surface Anomaly Detector	5	ZG3D - Multi-camera scanning systems, Tensorflow. Convolutional deep networks, Auto-encoders.	5	7
	Artificial Vision	5	Embedded machine vision system, AI deep learning tools, GANs, IIoT connectivity, ZDMP Non-Destructive Inspection	5	7
	AR-enhanced Inspector	5	Multi-camera object detection, Mobile Camera object detection, AR-Rendering, UI for target-actual-comparison	5	7
Thermal Inspection Suite	Heat Transfer Digital Twin	6	Heat Transfer, FEA modelling, Material Characterization, Thermal Map, Analytics	5	7

	IR Thermal Imaging	6	Thermal monitoring, Thermal cameras, AI toolkit, PAM2 (Packaging Analytical Monitoring2)	6	7
	Welding Process Monitoring	6	Thermal cameras, high current probes, voltage probes, wire speed sensors, high speed data acquisition, embedded processors, data analytics & AI tools	5	7

4.3 Mechanical Hardness Inspector

Explanation for end-users:

With this solution, the end-user will be able to measure mechanical properties or characteristics, microstructure and hardness profile, which are generated inside the workpiece during the induction hardening manufacturing process, without cutting the workpiece. The inspections will be performed in real time and on each manufactured component.

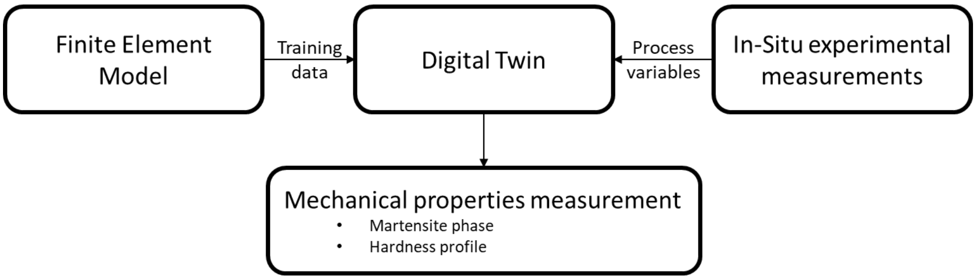

FIGURE 19: ZDZW MECHANICAL HARDNESS INSPECTOR

The hardness inspector (Figure 19) will be a manufacturing process digital twin, trained by data generated with a finite element model and complemented with some easy to measure process variables, such as surface temperature and machine process variables. The digital twin development will be performed with machine learning methods and the in-situ experimental measurement will be provided by commercial specific sensors.

WHAT: Features:

- Inside workpiece inspection
- Martensite formation % from surface to core
- Hardness profile
- Inspection in all manufactured components

WHO: Main expected users are:

Manufacturers that have implemented induction heat treatment process on their factory. Adaptation will be required for new geometries and materials. The same digital twin approach could be used for other manufacturing processes if a process finite element model is available.

INPUTS: Sensor technologies employed:

- Finite element model
- Pyrometers for surface temperature

- Current probe for coil intensity and frequency

OUTPUTS: Results your solution will provide users:
- Hardened case depth
- Martensite fraction inside the part
- Hardness profile inside the part

DEPENDENCIES: Technological basis for your development:
- Internal:
  - MATLAB
- External:
  - Platform integration

4.4 AE-Based Integrity Evaluator

Explanation for end-users:
This solution (Figure 20) will allow end-users to monitor the internal changes of a component, whatever the material it is made of. Metals, composites, wood, or any other material will show acoustic activity when it is exposed to external stimulus. The waves generated in these acoustic events contain information about the severity of the changes (damage), their location, and the mechanisms that generate them.
The AE technology will permit the detection of flaw propagations, metal yielding, fibre or matrix breakage in composites, delamination, microstructure changes (steel phase changes), bearing roller/raceway imperfections, and many more.

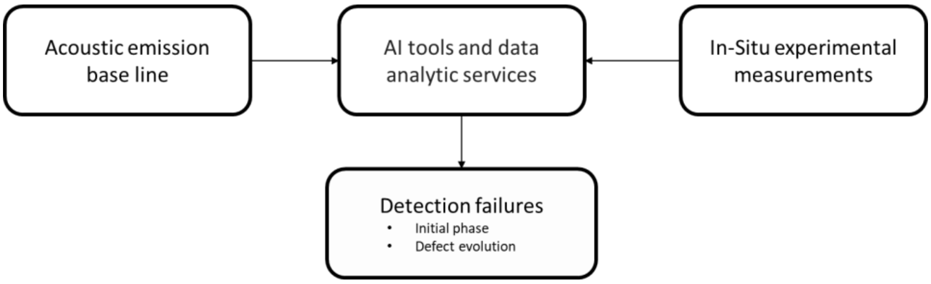

FIGURE 20: ZDZW AE-BASED INTEGRITY EVALUATOR

WHAT: Features:
- Inline inspection
- Damage detection/location/quantification
- Material properties estimation
- Volumetric technology
- Earlier fault detection due to its higher sensitivity

WHO: Main expected users are:
There are two main ways of using the acoustic emissions integrity evaluator: Components quality assessment and wear detection. The main industrial sectors can be overly broad: industrial machinery, metal production, pressure vessels, storage tanks, aircraft structures, steel cables, motorsport, bridge/building construction, etc.

INPUTS: Sensor technologies employed:
- Acoustic emission sensors
- Load cells
- Pyrometers

OUTPUTS: Results your solution will provide users:
- Damage detection

- Damage location
- Damage quantification
- Internal microstructure composition through DT.

DEPENDENCIES: Technological basis for your development:

- Internal:
  - Sensors and acquisition system
  - Software for model development (BigML, Python...)
- External:
  - Platform integration

4.5 MIR-OCT Solution

Explanation for end-users:

This solution will allow end-users to monitor the internal changes of a component in respect of the refractive index and thus inhomogeneities seen by the mid-infrared light probing the sample. The solution can be utilized for all materials that do not present a strong absorption in the four µm wavelength range. This includes many materials such as popular industrial ceramics, alumina and zirconia, paints, coatings and fibre-based materials such as paper and reinforced fibres.

The solution (Figure 21) will allow the user to detect microscopic changes in the bulk of the component which is particularly interesting when evaluating material quality in terms of homogeneity and number and type of detects. It is also interesting for a user to be able to visualize and follow any intended structures such as fibre-directions, channels, layers, voids and interfaces in general in depth of the component.

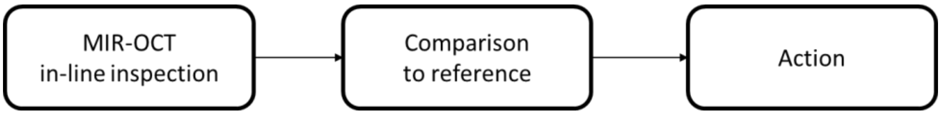

FIGURE 21: ZDZW MIR-OCT SOLUTION

WHAT: Features:

- Inline inspection
- Microscopic damage detection/location/quantification
- Material refractive index properties estimation
- Volumetric technology
- Earlier fault detection due to its higher penetration depth (in contrast to applying near-infrared light)

WHO: Main expected users are:

Main users include coating inspectors which encompasses all coating and painting industries targeting characterization of layer thickness, adhesion and defect localization but also players in industrial printing industries of plastics and ceramics that can benefit from tracing layer-to-layer transitions and identifying internal detects in the prints.

INPUTS: Sensor technologies employed:

- Mid-infrared spectrometer
- Visible camera

OUTPUTS: Results your solution will provide users:

- Damage detection by AI algorithms.
- Damage location by AI algorithms.
- Damage quantification by AI algorithms.

- Internal microstructure composition through spectrometer evaluation.

DEPENDENCIES: Technological basis for your development:
- Internal: Mid-infrared supercontinuum lasers
- External: Mid-infrared spectrometer

4.6 EMAT UT Solution

Explanation for end-users:

This solution (Figure 22) allows end-users to inspect the multi-pass welding at real-time during the manufacturing stage. This means that the welding process will not continue when a defect occurs in one pass of the entire process, improving significatively the current manufacturing process by reducing time and energy consumption as well as total waste.

An EMAT ultrasonic-based inspection system integrated into the welding device will inspect the welding pass-by-pass, to detect volumetric and surface defects through AI algorithms. The inspection system can be set up to stop the welding process once any discontinuity is detected, allowing to repair it before adding more welding passes.

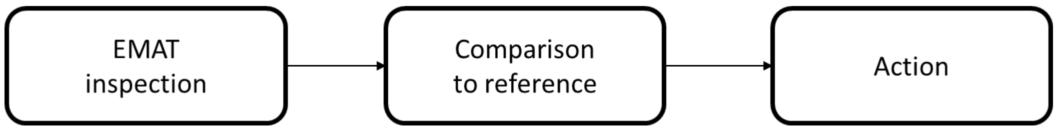

FIGURE 22: ZDZW EMAT UT SOLUTION

WHAT: Features:
- Inline hot temperature inspection
- Real time welding control
- Easily integrable
- Wide range of defect detection

WHO: Main expected users are:

Manufacturing industries that need to ensure a high degree of structural integrity in elements that include multi-pass welds due to the structural liability of the elements themselves or the customer specifications. For example, the renewable energy industry (wind turbine towers), Oil & Gas, nuclear, and metal products manufacturing amongst others.

INPUTS: Sensor technologies employed:
- EMAT sensors
- Positioning system

OUTPUTS: Results your solution will provide users:
- Different welding defects detection by AI algorithms.
- Location of welding defects detection by AI algorithms.
- Production alerts

DEPENDENCIES: Technological basis for your development:
- Internal:
  - C++ for software
  - Coils design
- External:
  - Coils manufacturing
  - PLC integration

4.7 Volumetric Inspector

Explanation for end-users:

This solution (Figure 23) allows end-users to compare the shape of inline produced goods with their intended design, highlighting differences between them. This prevents further integration of defective pieces in the final product, reducing total waste and energy consumption.

An in-line camera-based inspection device inspects produced goods, to detect volumetric defects. The algorithms designed will align the captured model with CAD design measuring deviations and estimating excessive and missing material in the inspected object.

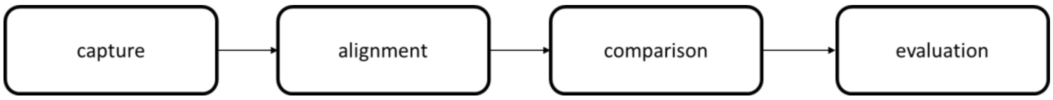

FIGURE 23: ZDZW VOLUMETRIC INSPECTOR

WHAT: Features:

- Inline inspection
- Captured object alignment
- Shape comparison
- Deviation evaluation

WHO: Main expected users are:

Manufacturing industries that require a quality assessment stage, either because they are part of a larger assembly, or the end customer requires a specific precision. For example, the automotive industry, plastic parts, machining, aeronautics, among others.

INPUTS: Sensor technologies employed:

- Vision cameras
- Illumination system
- Means of positioning the object
- CAD model

OUTPUTS: Results your solution will provide users:

- Located volumetric differences
- Production quality trends
- Production alerts
- Classification system

DEPENDENCIES: Technological basis for your development:

- Internal:
  - OpenCV
  - ZMQ
  - VisionLib
  - PyTorch
- External:
  - OPC-UA
  - MQTT
  - MODBUS

4.8 Surface Anomaly Detector

Explanation for end-users:

This solution (Figure 24)allows end-users to compare the texture of inline produced goods with a sample of previously inspected samples whilst highlighting abnormal regions. This prevents further integration of defective pieces in the final product, reducing total waste and energy consumption.

An in-line camera-based inspection device inspects produced goods, to detect surface anomalies. The algorithm will be trained with a sample of non-defective pieces to learn the correct visual aspect. The algorithms designed will align the captured images with learned model detecting anomalies in the surface of the inspected target.

FIGURE 24: ZDZW SURFACE ANOMALY DETECTOR

WHAT: Features:

- Inline inspection
- Captured object alignment
- Surface texture learning
- Surface anomaly detection
- Deviation evaluation

WHO: Main expected users are:

Manufacturing industries that require a quality assessment stage, either because they are part of a larger assembly, or the end customer requires a specific precision. For example, the automotive industry, plastic parts, machining, aeronautics, among others.

INPUTS: Sensor technologies employed:

- Vision cameras
- Illumination system
- Means of positioning the object
- Pre-inspected non-defective samples

OUTPUTS: Results your solution will provide users:

- Located surface anomalies
- Production quality trends
- Production alerts
- Classification system
- Learned surface model

DEPENDENCIES: Technological basis for your development:

- Internal:
  - OpenCV
  - ZMQ
  - Scikit-learn
  - TensorFlow
  - Keras
  - PyTorch
  - External
  - OPC-UA
  - MQTT
  - MODBUS

4.9 Artificial Vision

Explanation for end-users:

Artificial vision solutions (Figure 25) allow the extraction of features of interest from a digital image which can be processed for further analysis, such as dimensional control or defect detection. In industrial applications these controls can be used to assess the quality and conformity of products and eventually automate related decisions (eject, rework, …). AI techniques can also be integrated to extend the potential and applicability of AV solutions.

2D Camera based embedded systems located in-line allow inspection of products, extract characteristic features, check their geometry, size, and relative position, measure defined dimensions, etc. This enables the final assessment of production quality and track relevant parameters in time.

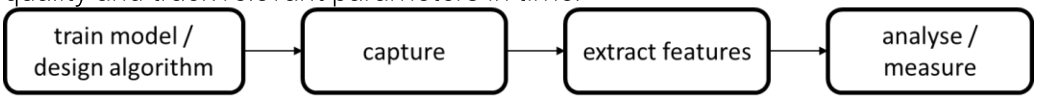

FIGURE 25: ZDZW MECHANICAL HARDNESS INSPECTOR

WHAT: Features:

- Inline inspection
- Algorithm Design
- Integration of AI techniques if needed (deep-learning, GAN, autoencoder, segmentation, …)
- High-throughput analysis

WHO: Main expected users are:

Manufacturing industries that require a quality assessment stage, either because they are part of a larger assembly, or the end customer requires a specific precision. For example, the automotive industry, plastic parts, machining, aeronautics, hollow glass producers, flat glass producers, steel makers and other sectors that needs to automate visual inspection of goods.

INPUTS: Sensor technologies employed:

- 2D Camera(s)
- Illumination systems
- Embedded system for fast image processing

OUTPUTS: Results your solution will provide users:

- Dimensional/position check
- Shape feature control
- Defect detection
- Surface quality inspection
- Production quality trends and alerts

DEPENDENCIES: Technological basis for your development:

- Internal:
    - OpenCV
    - Scikit-learn
    - PyTorch
    - MongoDB
    - MinIO
- External:
    - OPC-UA
    - AMQP/MQTT

- MODBUS/MODBUS IP

4.10 AR enhanced Inspector

Explanation for end-users:

Augmented Reality (Figure 26) allows visualizing information for human beings by superimposing it over the real scene. This is for instance performed by utilizing a head-mounted-display or a hand-held device, like a tablet. Object-detection-technologies find the objects of interest in the current field-of-view to draw localized information in the scene, e.g., pointing out defects on a previously inspected object.

In ZDZW this technology is used to assist inspectors and workers in evaluating and fixing automatically detected defects, by blending the defects' locations and any additional information directly into their fields of view. This allows a more intuitive and thus faster and more accurate processing of detected defects, than mere images or textual checklists. Additionally, the Augmented Reality-based system will allow users to take pictures and annotate them, throughout the process, to document it.

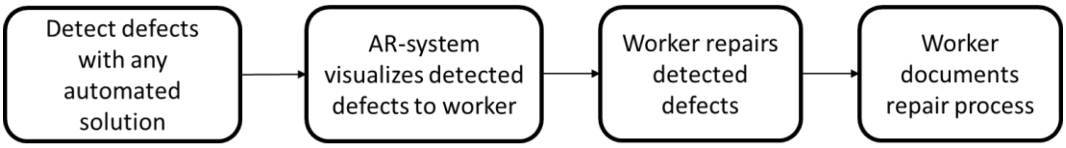

FIGURE 26: ZDZW AR ENHANCED INSPECTOR

WHAT: Features:

- Augmented-Reality-based interaction using tablets or head-mounted-displays
- Assistance for inspection- and repair-processes
- Defect visualization
- Process documentation via text and images

WHO: Main expected users are:

Anyone who either manually inspects a product or manually fixes automatically detected defects and can benefit from assistance in the form of additional information superimposed on the visible scene. e.g., workers needing to locate defects, which have been automatically detected before.

INPUTS: Sensor technologies employed:

- Camera(s)
- CAD-Model

OUTPUTS: Results your solution will provide users:

- Superimposed visualization of inspection results.
- Using either video- or optical-see-through devices or projectors, depending on the use-case.

DEPENDENCIES: Technological basis for your development:

- OpenCV
- VisionLib
- PyTorch
- External
- MQTT

Funded by the European Union

4.11 Thermoforming Digital Twin Solution

Explanation for end-users:

End users, especially those using heavy-gauge thermoforming processes, will have the ability to get three-dimensional temperature field of plastic sheets. Depending on the material properties, geometry definition and initial conditions, this inspector relies on a Digital Twin that is optimized with radiative heat transfer calculations and sensor data from the pyrometers on the thermoforming machine.

Using this solution (Figure 27), target temperature maps will be reversed to heating elements automatic setup. In case of varying factory conditions and material definitions, the system will be automatically calibrating itself compared to manual intervention of the operator.

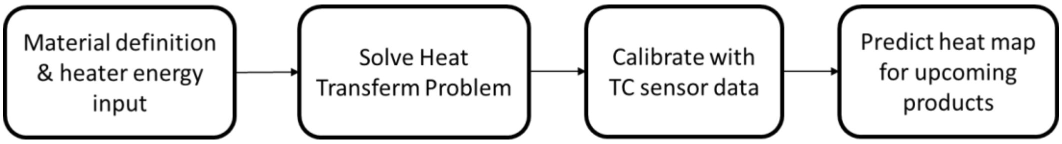

FIGURE 27: ZDZW THERMOFORMING DIGITAL TWIN SOLUTION

WHAT: Features:

- 3D Sheet Temperature Field Estimator
- Reverse heating element pattern calculator
- Formability predictor
- Defective heating element compensator

WHO: Main expected users are:

Appliances, white-goods, FMCG, Automotive and Aviation Industries rely on thermoformed products. Either thin gauge (for example: packaging) or heavy gauge (for example: refrigerator liner) thermoforming is used, quality of the end product and elimination of defected goods will be possible since transient thermal predictions will be possible with this technology.

INPUTS: Sensor technologies employed:

- Temperature sensors
- Thermal Camera
- Proximity Sensors

OUTPUTS: Results your solution will provide users:

- Users have the visuals of the full thermal map of the plastic sheets
- Desired temperature pattern on the sheets is setup as a reverse problem to estimate the heaters' setup
- In case of the heater failure, compensation is possible by calibrating neighbouring heating elements

DEPENDENCIES: Technological basis for your development:

- Finite Element Solvers
- Python, Fortran
- External
- Modbus
- MQTT
- OPC-UA

4.12 Thermal Imaging Inspector

Explanation for end-users:

The integrity of the heat-sealing process in a primary package is critical to the safety of the public. If there are defects in the sealing structure, the product will be contaminated by the outside environment. The primary package is usually made of plastic and aluminium and both materials generate waste which is extremely hard to recycle.

Thermal imaging (Figure 28) combined with AI enables real time process control since it can monitor the heated sealing pattern that standard vision cameras cannot reveal and alert on time when there is a degradation in the process. This enables waste and defect reduction in this critical process.

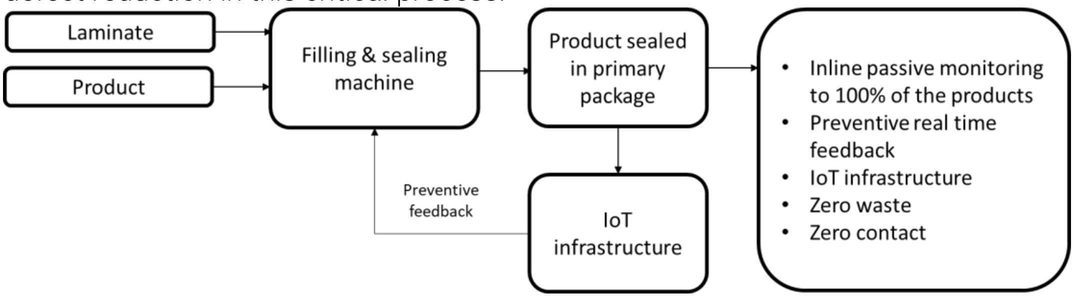

FIGURE 28: ZDZW THERMAL IMAGING INSPECTOR

WHAT: Features:

- Inline inspection
- Algorithm Design
- SPC and dashboard charts

WHO: Main expected users are:

Manufacturing industries that are interested in waste reduction, sustainability and process integrity during the filling and primary packaging phase in the food, beverages, pharma, cosmetics and medical devices industries.

INPUTS: Sensor technologies employed:

- Thermal imaging cameras
- Photo sensors

OUTPUTS: Results your solution will provide users

- Thermal sealing dimensional check
- Shape feature control
- Defect detection
- Thermal sealing intensity uniformity
- Production quality trends and alerts

DEPENDENCIES: Technological basis for your development:

- Internal:
  - OpenCV
  - PLC programming
- External:
  - Mechanical and electronic design

4.13 Welding Process Inspector

Explanation for end-users:

The Welding Process Inspector aims to reduce the quality inspection iterations and the rework time by early warning about the possible presence of defects during the welding process. This solution relies on two main pillars: HW and SW. The solution is based on a real-time on-line monitoring system, envisioned from a multimodal perspective, i.e., the system has the flexibility to connect to a range of heterogeneous sensors and devices through different communication protocols. All the data is registered temporally and spatially, resulting in a Digital Twin of the welding process containing the real variables of the "manufacturing" of the weld seams. The second pillar of the solution is the real time data processing of the monitored data to throw warnings alerting of the possible presence of a defect during the welding process. To know which defects can be detected using available sensors and to assess the accuracy of the detections, a great amount of data and a deep knowledge of the process is needed.

FIGURE 29: ZDZW WELDING PROCESS INSPECTOR

WHAT: Features:

- Welding monitoring
- Sensor data integration
- Visual representations
- Quality control

WHO: Main expected users are:

Manufacturing industries that need to ensure a high degree of structural integrity in elements that include multi-pass welds due to the structural liability of the elements themselves or the customer specifications and warranties. For example, the renewable energy industry (wind turbine towers).

INPUTS: Sensor Technologies employed:

- Edge computing
- Welding sensors (e.g., Current probes, voltage probes, wire speed sensors)
- IR thermal imaging systems
- AI for quality control

OUTPUTS: Results your solution will provide users:

- Platform to generate Digital Twins of welding processes.

DEPENDENCIES: Technological basis for your development:

- Internal:
  - C++ software
  - Edge computing libraries, OpenCV
- External:
  - OPC-UA

4.14 Marketplace

Explanation for end-users:

ZDZW Applications of WP4-6 must, and will, be available through ZDZW Marketplace(s) it a similar model to other marketplaces such as Google Play. These opportunities enable developers to create and distribute applications and earn revenue with maximum geographic reach. Similarly manufacturing users are able to access applications easily, economically, and with less dependencies of their locality. It will enable different licensing models, user comments, and ratings. The marketplace will go "beyond the Apple App Store;" it will offer end-users the possibility for advanced subscription-based models (pay as-you-go, pay per-use, pay per zero-waste saved, etc.).

The Marketplace (Figure 30) will be integrated to the ZDZW secure usage traceability for monetisation service to guarantee trustworthy usage data and provide visibility such that end-users can visualize ongoing costs per application through exposure/embedding technology/functionality of the usage traceability task. Users will of course perform payments, by means of third-party secure payment gateways with the Application owner credited for sales as well as the Marketplace owner taking an approximate 15% commission online with other marketplaces. Sufficient accounting features will be provided. Marketplace(s) implies there may be Multiple ZDZW Marketplaces (e.g., Geographics, Domain) include a link with an existing commercial Marketplace were example linking will be made so that Vice-versa, other platforms users should be able to easily buy and use ZDZW application/services.

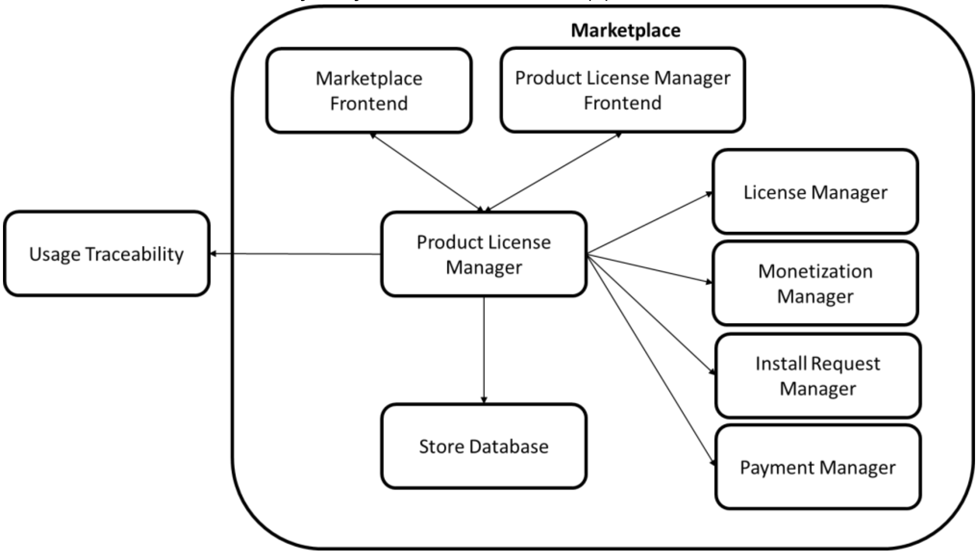

FIGURE 30: ZDZW MARKETPLACE

WHAT: Features:

- Typical Marketplace features:
  - Product Upload (Descriptions, Images, Pricing, Conditions…)
  - Purchase Option (Full Use, Restriction use, Free use…)
  - Support multiple costs models - e.g., licensing (Product ownership), Time subscriptions, Usage (e.g., Volume)
  - Secure Deployment linked with Platform

- Support of several marketplaces
WHO: Main expected users are: - Manufacturing users of all kinds who wish to request, select, purchase, deploy, use ZDZW (compatible) applications either as Licenses, Subscriptions, or pay-per-use models - Technology developers (where there is a software component) who wish to engage with users to develop new applications and/or to make those applications available to purchase from Manufacturing users. Within the Project this mandatorily includes all technologies developed in WP4-6 so that each is on the marketplace and deployable/usable in a certain way
INPUTS: Sensor Technologies employed: - Not Applicable
OUTPUTS: Results your solution will provide users: - Fully functional and operational Marketplace, tailored to ZDZW specific needs, to purchase Applications/Subscriptions/Services with normal marketplace features for both users and provides of 'goods' on the marketplace

DEPENDENCIES: Technological basis for your development:
- Internal:
  - Product Definition file
  - Existing Marketplace Open Source and IPR from ZDMP (includes vf-OS concepts)
  - Existing Commercial Marketplace under development from FFIT
- External:
  - ZDMP Marketplace
  - FFIT Marketplace
  - EFPF Marketplace consolidator link (possibly)

4.15 Platform

Explanation for end-users: The ZDZW Platform (Figure 31) is the home base for all kind of services and middleware to support other WPs as identified in Section 0 on Message & Service Bus as well as Interlinking. It is based on ZDMP (precursor EU project) as a core platform and enable the containerised version of other components and all outwards facing applications to support the project and future commercial use cases in a secure, decentralised, In-Cloud / On-Premise, Fog / Edge enabled and scalable environment. WP4-6 will mandatorily need to invoke in their 'applications' relevant technology to ensure they can run on the platform. Extensive use of Docker/Kubernetes in a containerisation strategy will allow easier user deployments. It will contain possibilities for collaboration of all parties and developers throughout the project. The service-oriented platform is expected to support the interoperability with other platforms or infrastructure elements at user sites 'developed' through the Interlinking Facility. The technologies connected with the Platform are not the core RTD of ZDZW but a set of common necessary features to enable WP4-6 for wider deployment and scalable usage adapted as necessary for ZDZW specifics. As such, a sizeable portion of the task will be supporting those such developers will do this. Related to this is an extensive budget to support platform and application hosting held by IKERLAN.

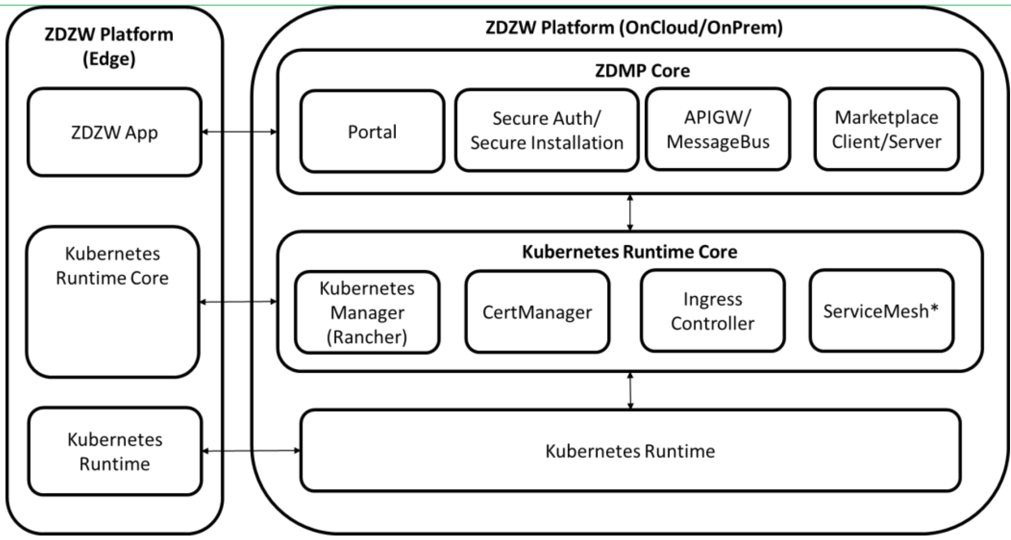

FIGURE 31: ZDZW PLATFORM

WHAT: Features:

- In-Cloud / On-Premise with Fog/Edge and IT Mesh support/exploration
- Deployment Neutrality (Including addition of Raspberry Pi (similar) to support sensors in particular
- Scalable, Secure, Decentralised
- Partner Collaboration
- Service Orientated (Service-related Technologies)

WHO: Main expected users are:

- Manufacturing users of all kinds who wish to deploy ZDZW (compatible) applications in different platform environments (e.g., Windows, Linux), and situations (In-Cloud, On-Premise). Within the context of the project this includes all the pilot cases
- Technology developers (where there is a software component) who wish to develop platform independent ZDZW orientated applications and components. Within the Project this mandatorily includes all technologies developed in WP4-6

INPUTS: Sensor Technologies employed:

- Not Applicable

OUTPUTS: Results your solution will provide users:

- Ability to run applications In-Cloud, On-Premise, Fog/Edge and in a scalable and secure way, whilst being deployable on multiple environments
- Ability for supply chain manufacturing users as well as users and technology provide to collaborate – for example resolving issues or suggesting new features

DEPENDENCIES: Technological basis for your development:

- Internal:
  - Docker
  - Kubernetes
  - ZDMP Platform
  - ZDMP Engagement Hub (Possibly)
  - Hosted Hardware Environment
  - Service Mesh Technologies

  - Raspberry PI (and Similar)
  - Each development of WP4-6 to mandatorily support the platform technologies/components including at least the following. This is a requirement on those developments rather than the platform:
  - Application Runtime (Kubernetes, Helm Charts, Docker)
  - Portal (Dash Button, Secure Auth, Security)
  - Marketplace (In conjunction with Marketplace subsection 4.14 of this document): Add specific annotations to Kubernetes yaml files
  - API Gateway: API calls and security as Well as Message Bus: RabbitMQ (In conjunction with Interlinking/Messaging subsections 4.16-4.17 of this document)
- External:
  - ZDMP Platform
  - ZDMP Engagement Hub (Possibly)
  - Hosted Hardware Environment

4.16 Interlinking

Explanation for end-users:

The Interlinking (Figure 32) component's aim is to link ZDZW with other external platforms. This will, for example, support the ability to sell ZDZW services to other platforms and buy other components or services from those. It also includes a layer to link data sources from different platforms and integrates security between the platforms to ensure appropriate access procedures across the platforms also including connections to other instances of ZDZW in case e.g., not only one single instance is used at user (customer) side but many on different factory locations.

The component aims to manage three main concepts: Data, Marketplace, and Security. It expects to link to the platform (machine data and marketplace information) of the EU funded projects ZDMP, EFPF (formally known as eFactory), the commercial platforms ADAMOS IIoT platform, Bosch IoT Suite and Servitly. Further platform linkages will be investigated as the project progresses and depends on user requests.

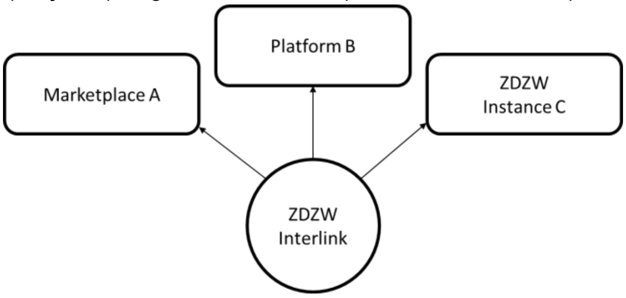

FIGURE 32: ZDZW INTERLINKING

WHAT: Features:

- Interlink to other manufacturing platforms and/or marketplaces via linking to the corresponding APIs
- Service Orientated (Service-related Technologies)

WHO: Main expected users are:

• Manufacturing users of all kinds who wish to make use of information (sensor data, machines, marketplace offerings) of other platforms or another instance of ZDZW. Within the context of the project this includes dedicated pilot cases • Technology developers (where there is a software component) who wish to develop features that are based on the usage of available APIs of ZDZW and external platforms
INPUTS: Sensor Technologies employed: • Not Applicable
OUTPUTS: Results your solution will provide users • Access to external platforms (including possible commercial platforms)

DEPENDENCIES: Technological basis for your development:
• Internal:
  ◦ ZDZW Service- and Message Bus
  ◦ ZDMP Interlinking
• External:
  ◦ ZDMP Platform
  ◦ Hosted Hardware Environment
  ◦ Further platform linkages will be investigated as the project progresses and depends on user requests

4.17 Messaging and Service bus

Explanation for end-users: The Services and Message Bus (Figure 33) represents the central communication layer of the ZDZW Platform. It provides the following main functions: • It acts as the central endpoint to all ZDZW APIs of all components/solutions and allows the convenient management of the APIs through a web-based interface. It can automatically update any API's service endpoint when installing a component on ZDZW and can automatically manage user authentication and authorization for the APIs. e.g., if an additional secure authentication component is in use, it can integrate with that. Furthermore, this component also supports the component Usage Traceability. • It provides ZDZW Assets with a message bus – a standardized communication interface to exchange messages, events, and data. This message bus implements a publish/subscribe messaging concept which allows the connected components to broadcast (publish) information on specific topics and to listen for certain events and topics (subscribe). Supported messaging protocols are MQTT and AMQP. This may be extended if requested or if during the project lifetime a new industry relevant protocol might become near-production-ready. It acts as an integration point of existing components that might already make use of a messaging system. In that case, the ZDZW message and service bus allows to connect this component easily to become part of the overall ZDZW architecture.

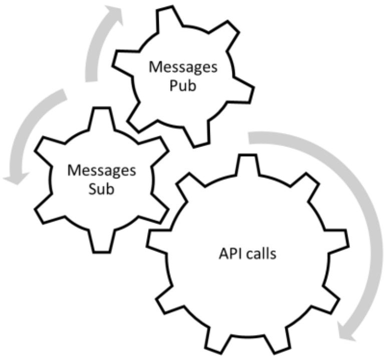

FIGURE 33: ZDZW MESSAGING AND SERVICE BUS

WHAT: Features:

- A message bus (RabbitMQ based) with pub/sub capabilities and support for several standard protocols (MQTT, AMQP)
- Service Orientated (Service-related Technologies)
- A central management of APIs

WHO: Main expected users are:

- Technology developers (where there is a software component) who wish to receiver or send messages (e.g., sensor data vice versa) through the ZDZW platform.
- Technology developers calling APIs of internal components

INPUTS: Sensor Technologies employed:

- Not Applicable

OUTPUTS: Results your solution will provide users:

- Access to all kind of messages and managed access to all ZDZW APIs of other components

DEPENDENCIES: Technological basis for your development:

- Internal:
  - ZDMP Service- and Message Bus
- External:
  - ZDMP Platform
  - Hosted Hardware Environment

4.18 Usage Traceability

Explanation for end-users:

The Usage Traceability (Figure 34) represents the central communication layer between the Marketplace, the Assets (applications users) and the ZDZW Blockchain. It provides the following main functions:

- Manages the smart contracts to be able to trace the usability of a ZDZW Inspection Solution
- Implements business logic to allow the usage data traceability and monetization management
- Stores in the ZDZW Blockchain the terms of the smart contract.
- Triggers payments according to the conditions implemented in the smart contract

- Tracks and store the usage of ZDZW applications by end-users in the Blockchain (BaaS)

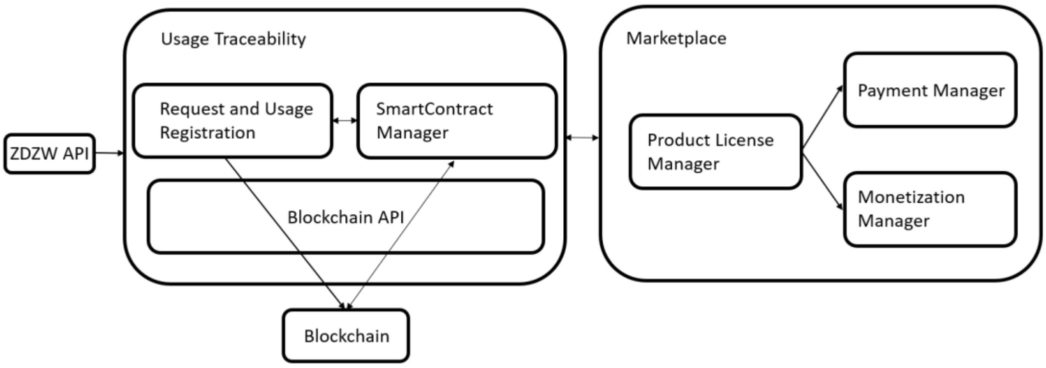

FIGURE 34: ZDZW MECHANICAL HARDNESS INSPECTOR

WHAT: Features:

- Request and Usage registration: The input data coming from the API will be filtered by the usage registration of the apps and the different requests done to the API
- Smart Contract Manager: Manages the definition Smart Contract parameters and condition and help to register these data in the blockchain. It provides the possibility of creating and modifying smart contracts
- Blockchain API: Access point to interact with the blockchain

WHO: Main expected users are:

- From a traceability point of view, there is no direct user since the process is managed transparently for the end user
- Users must interact with the Smart Contract Manager. A smart contract works in the same way as a physical contract, where several (always two or more) parties sign an agreement and define certain conditions. In this case, before publishing the smart contract, the users will have to reach agreements and define in the contract. The user interaction does not end here, since during the useful life of the contract it may be modified, and all parties will have to confirm them

INPUTS: Sensor Technologies employed:

- Not Applicable

OUTPUTS: Results your solution will provide users

- Apps usage data:
  - Requests made from the Apps to the API
  - Application usage times
  - Option to view blockchain logs

DEPENDENCIES: Technological basis for your development:

- Internal:
  - Docker
  - Kubernetes
  - Selected BaaS plugins and libraries
  - Programming language depends on selected BaaS (Python, Java, Go)
- External:
  - ZDMP Platform API Gateway
  - ZDMP Marketplace

- BaaS (Blockchain as a Service)
- IDE for services development (Visual Studio)

5 MILESTONES AND DELIVERABLES

All work packages have clear milestones, and all tasks have deliverables, which are the official outputs of the project. Several high-level milestones have been adopted ensuring that each major cycle of the project is completed on time.

The list of the project's milestones (M) is presented in the Table 8.

TABLE 8: LIST OF MILESTONES

Milestone Number & Name		WP	Date	Means of verification
M1	Project planning and management structure set-up	1	1	Project Planning Defined; Project Management Structure set-up; Project monitoring, control, quality and communication handbook available
M2	Project Vision Consensus	2	3	Project Vision Guide Document (D2.1) signed
M3	Project Dissemination Strategy implemented	10	3	Project Dissemination Strategy defined (D10.1a); ZDZW website set up and running; Release of the public part of the dissemination materials
M4	Data management plan developed	1	6	Data management plan signed by all (D1.6)
M5	Requirements identified and assessed	2	9	List of Requirements with average assessment valorisation completed (D2.3 and D2.4)
M6	Exploitation strategy developed	3	12	Exploitation strategy included in D3.2
M7	Freedom to operate of the KERs	3	12	Analysis report that confirms the FTO (D3.2)
M8	Skill development strategy defined	10	12	Skill development strategy included on D10.1
M9	Periodic Progress reports and cost statements released for PR1	1	18	Periodic Progress Reports including Financial Statements submitted and approved by EC
M10	Standardisation needs identified	3	18	Minutes of standardisation workshop and list of proposed standardisation needs (D3.6)
M11	ZDZW Inspection Solutions internal validation completed	4, 5, 6, 7	24	Video report of the ZDZW Inspection Solutions being used in test production
M12	LCA Hot spots identified	8	24	Value Chain Analysis completed (D8.1)

M13	ZDZW Inspection Solutions integration completed and running	9	24	Video of the ZDZW Inspection Solutions running in real production

The project's deliverables (D) are listed in the table below.

TABLE 9: List of deliverables

Deliverable Number & Name		WP	Lead	Type	Dissemination level	Date
D1.1	Project Handbook	1	IKER	R	EU Con	3
D1.2	Strategic and Operational Coordination - M12	1	IKER	R	EU Con	12
D1.3	Strategic and Operational Coordination - M24	1	IKER	R	EU Con	24
D1.4	Strategic and Operational Coordination - M36	1	IKER	R	EU Con	36
D1.5	Periodic Reports – M12	1	IKER	R	EU Con	12
D1.6	Periodic Reports – M24	1	IKER	R	EU Con	24
D1.7	Periodic Technical WP Reports – M12	1	ICE	R	EU Con	12
D1.8	Periodic Technical WP Reports – M24	1	ICE	R	EU Con	24
D1.9	Periodic Technical WP Reports – M36	1	ICE	R	EU Con	36
D1.10	Periodic Ops Setup and Quality Control Report – M12	1	ICE	R	EU Con	12
D1.11	Periodic Ops Setup and Quality Control Report – M24	1	ICE	R	EU Con	24
D1.12	Periodic Ops Setup and Quality Control Report – M24	1	ICE	R	EU Con	36
D1.13	Data Management Plan	1	ITI	DMP	EU Con	6
D1.14	Data Management Plan	1	ITI	DMP	EU Con	12
D1.15	Data Management Plan	1	ITI	DMP	EU Con	24
D1.16	Data Management Plan	1	ITI	DMP	EU Con	36
D2.1	Project Vision Document	2	IKER	R	PU	3
D2.2	Benchmarking of Sustainable Manufacturing Technol.	2	VSYS	R	PU	4
D2.3	Demonstration scenarios & KPIs definition – M4	2	UPV	R	EU Con	4
D2.4	Demonstration scenarios & KPIs definition – M9	2	UPV	R	EU Con	9
D2.5	Requirements Analysis and Functional Specification – M6	2	UPV	R	EU Con	6
D2.6	Requirements Analysis and Functional Specification – M12	2	UPV	R	EU Con	12
D3.1	Key Exploitable Results & Business Model Canvas	3	FBA	DEC	EU Con	6
D3.2	Plan for Exploitation & Dissem. of results-PEDR – M6	3	VIV	DEC	EU Con	6

D3.3	Plan for Exploitation & Dissem. of results-PEDR – M12	3	VIV	DEC	EU Con	12
D3.4	Plan for Exploitation & Dissem. of results-PEDR – M24	3	VIV	DEC	EU Con	24
D3.5	Plan for Exploitation & Dissem. of results-PEDR – M36	3	VIV	DEC	EU Con	36
D3.6	FTO Analysis Report – M12	3	VIV	DEC	EU Con	12
D3.7	FTO Analysis Report – M24	3	VIV	DEC	EU Con	24
D3.8	Report on End Users/Customers' Validation	3	FBA	R	EU Con	36
D3.9	Viability Plan	3	FBA	R	EU Con	36
D3.10	Standardization Plan and Status Report – M12	3	DIN	R	PU	12
D3.11	Standardization Plan and Status Report – M24	3	DIN	R	PU	24
D3.12	Standardization Plan and Status Report – M36	3	DIN	R	PU	36
D4.1	ZDZW Mechanical Hardness Inspector – M18	4	IKER	OTHER	PU	18
D4.2	ZDZW Mechanical Hardness Inspector – M24	4	IKER	OTHER	PU	24
D4.3	ZDZW Mechanical Hardness Inspector – M36	4	IKER	OTHER	PU	36
D4.4	ZDZW AE-based Integrity Evaluation – M18	4	IKER	OTHER	PU	18
D4.5	ZDZW AE-based Integrity Evaluation – M24	4	IKER	OTHER	PU	24
D4.6	ZDZW AE-based Integrity Evaluation – M36	4	IKER	OTHER	PU	36
D4.7	ZDZW MIR-OCT Solution – M18	4	NOR	OTHER	PU	18
D4.8	ZDZW MIR-OCT Solution – M24	4	NOR	OTHER	PU	24
D4.9	ZDZW MIR-OCT Solution – M36	4	NOR	OTHER	PU	36
D4.10	ZDZW EMAT UT Solution – M18	4	INN	OTHER	PU	18
D4.11	ZDZW EMAT UT Solution – M24	4	INN	OTHER	PU	24
D4.12	ZDZW EMAT UT Solution – M36	4	INN	OTHER	PU	36
D5.1	ZDZW Volumetric Inspector – M18	5	ITI	OTHER	PU	18
D5.2	ZDZW Volumetric Inspector – M24	5	ITI	OTHER	PU	24
D5.3	ZDZW Volumetric Inspector – M36	5	ITI	OTHER	PU	36
D5.4	ZDZW Surface Anomaly Detector – M18	5	ITI	OTHER	PU	18
D5.5	ZDZW Surface Anomaly Detector – M24	5	ITI	OTHER	PU	24
D5.6	ZDZW Surface Anomaly Detector – M36	5	ITI	OTHER	PU	36
D5.7	ZDZW Artificial Vision – M18	5	VSYS	OTHER	PU	18
D5.8	ZDZW Artificial Vision – M24	5	VSYS	OTHER	PU	24
D5.9	ZDZW Artificial Vision – M36	5	VSYS	OTHER	PU	36
D5.10	ZDZW AR Inspector – M18	5	IGD	OTHER	PU	18
D5.11	ZDZW AR Inspector – M24	5	IGD	OTHER	PU	24
D5.12	ZDZW AR Inspector – M36	5	IGD	OTHER	PU	36

D6.1	ZDZW Heat Transfer Process Digital Twin – M18	6	SIM	OTHER	PU	18
D6.2	ZDZW Heat Transfer Process Digital Twin – M24	6	SIM	OTHER	PU	24
D6.3	ZDZW Heat Transfer Process Digital Twin – M36	6	SIM	OTHER	PU	36
D6.4	ZDZW IR Thermal Imaging – M18	6	YOR	OTHER	PU	18
D6.5	ZDZW IR Thermal Imaging – M24	6	YOR	OTHER	PU	24
D6.6	ZDZW IR Thermal Imaging – M36	6	YOR	OTHER	PU	36
D6.7	ZDZW Welding Process Monitoring – M18	6	AIM	OTHER	PU	18
D6.8	ZDZW Welding Process Monitoring – M24	6	AIM	OTHER	PU	24
D6.9	ZDZW Welding Process Monitoring – M36	6	AIM	OTHER	PU	36
D7.1	Development Environment Activity/Reporting – M18	7	ICE	R	PU	18
D7.2	Development Environment Activity/Reporting – M24	7	ICE	R	PU	24
D7.3	Development Environment Activity/Reporting – M36	7	ICE	R	PU	36
D7.4	Interoperability Platform – M18	7	SAG	OTHER	PU	18
D7.5	Interoperability Platform – M24	7	SAG	OTHER	PU	24
D7.6	Interoperability Platform – M36	7	SAG	OTHER	PU	36
D7.7	Platform and Marketplace Interlinking – M18	7	ICE	OTHER	PU	18
D7.8	Platform and Marketplace Interlinking – M24	7	ICE	OTHER	PU	24
D7.9	Platform and Marketplace Interlinking – M36	7	ICE	OTHER	PU	36
D7.10	Usage Traceability for Monetization Service – M18	7	IKER	OTHER	PU	18
D7.11	Usage Traceability for Monetization Service – M24	7	IKER	OTHER	PU	24
D7.12	Usage Traceability for Monetization Service – M36	7	IKER	OTHER	PU	36
D7.13	Cross WP integration – M18	7	ICE	OTHER	PU	18
D7.14	Cross WP integration – M24	7	ICE	OTHER	PU	24
D7.15	Cross WP integration – M36	7	ICE	OTHER	PU	36
D8.1	Value Chain Analysis and Hot-Spot-Screening	8	EUR	R	PU	24
D8.2	Life Cycle and Cost Analyses	8	EUR	R	PU	36
D8.3	Eco-Efficiency and Comparison to State-of-the Art	8	EUR	R	PU	36
D8.4	Social impact assessment and technology acceptance	8	ZIC	R	PU	36
D9.1	Pilot 1: Plastic Parts Mass Production Quality Assurance – M18	9	GLN	DEM	EU Con	18
D9.2	Pilot 1: Plastic Parts Mass Production Quality Assurance – M24	9	GLN	DEM	EU Con	24

D9.3	Pilot 1: Plastic Parts Mass Production Quality Assurance – M30	9	GLN	DEM	EU Con	30
D9.4	Pilot 1: Plastic Parts Mass Production Quality Assurance – M36	9	GLN	DEM	EU Con	36
D9.5	Pilot 2: Thermoplastics Forming Excellence – M18	9	ARC	DEM	EU Con	18
D9.6	Pilot 2: Thermoplastics Forming Excellence – M24	9	ARC	DEM	EU Con	24
D9.7	Pilot 2: Thermoplastics Forming Excellence – M30	9	ARC	DEM	EU Con	30
D9.8	Pilot 2: Thermoplastics Forming Excellence – M36	9	ARC	DEM	EU Con	36
D9.9	Pilot 3: Wind Turbine Tower Production Enhancement – M18	9	GRI	DEM	EU Con	18
D9.10	Pilot 3: Wind Turbine Tower Production Enhancement – M24	9	GRI	DEM	EU Con	24
D9.11	Pilot 3: Wind Turbine Tower Production Enhancement – M30	9	GRI	DEM	EU Con	30
D9.12	Pilot 3: Wind Turbine Tower Production Enhancement – M36	9	GRI	DEM	EU Con	36
D9.13	Pilot 4: Durable Fastening Solutions Production – M18	9	ERRE	DEM	EU Con	18
D9.14	Pilot 4: Durable Fastening Solutions Production – M24	9	ERRE	DEM	EU Con	24
D9.15	Pilot 4: Durable Fastening Solutions Production – M30	9	ERRE	DEM	EU Con	30
D9.16	Pilot 4: Durable Fastening Solutions Production – M36	9	ERRE	DEM	EU Con	36
D9.17	Pilot 5: Lithography-based eHealth Parts Production – M18	9	AIR	DEM	EU Con	18
D9.18	Pilot 5: Lithography-based eHealth Parts Production – M24	9	AIR	DEM	EU Con	24
D9.19	Pilot 5: Lithography-based eHealth Parts Production – M30	9	AIR	DEM	EU Con	30
D9.20	Pilot 5: Lithography-based eHealth Parts Production – M36	9	AIR	DEM	EU Con	36
D9.21	Pilot 6: Coffee capsule AV AI-based quality control – M18	9	ILLY	DEM	EU Con	18
D9.22	Pilot 6: Coffee capsule AV AI-based quality control – M24	9	ILLY	DEM	EU Con	24
D9.23	Pilot 6: Coffee capsule AV AI-based quality control – M30	9	ILLY	DEM	EU Con	30
D9.24	Pilot 6: Coffee capsule AV AI-based quality control – M36	9	ILLY	DEM	EU Con	36
D9.25	Open Pilot: Beta Testing Camp – M18	9	IKER	R	EU Con	18
D9.26	Open Pilot: Beta Testing Camp – M24	9	IKER	R	EU Con	24
D9.27	Open Pilot: Beta Testing Camp – M30	9	IKER	R	EU Con	30
D9.28	Open Pilot: Beta Testing Camp – M36	9	IKER	R	EU Con	36

Funded by the European Union

D9.29	Impact assessment and KPI validation of ZDZW solutions – M18	9	AIM	R	PU	18
D9.30	Impact assessment and KPI validation of ZDZW solutions – M24	9	AIM	R	PU	24
D9.31	Impact assessment and KPI validation of ZDZW solutions – M30	9	AIM	R	PU	30
D9.32	Impact assessment and KPI validation of ZDZW solutions – M36	9	AIM	R	PU	36
D10.1	Target-Driven Dissemination Strategy, Plan & Reporting – M3	10	UPV	R	PU	3
D10.2	Target-Driven Dissemination Strategy, Plan & Reporting – M12	10	UPV	R	PU	12
D10.3	Target-Driven Dissemination Strategy, Plan & Reporting – M24	10	UPV	R	PU	24
D10.4	Target-Driven Dissemination Strategy, Plan & Reporting – M36	10	UPV	R	PU	36
D10.5	Policy Recommendations	10	ZAB	R	PU	36
D10.6	Target-Driven Dissemination Strategy, Plan & Reporting – M3 - Website	10	UPV	DEC	PU	3

6 RISKS

The critical implementation risks and mitigation actions of the project are presented below:

TABLE 10: LIST OF RISKS AND MITIGATIONS

Description of risk	Likelihood	Severity	WP	Proposed risk-mitigation measures
Failures to meet milestones	Low	Med	1	The project management includes high visibility of progress, early identification of problems and risks, and allows quick response to changes
Poor coordination or communication	Low	Med	1	The PC has adequate knowledge and experience in managing projects and all participants have already participated in several projects.
Under/over effort estimation	High	Low	1	Monitoring the planned versus the actual effort required by each task. Indicators and statistics will be included in the PPRs.
Deliverable failure due to missed deadline or poor deliverable quality	Low	Med	1	WPL will overview their related tasks and deliverables. The TM will make a final check of the deliverables for consistency and readability. Where necessary, WPL, TM and PC can request further work from partners on a deliverable, to ensure that compliance with the contractual requirements.
Lack of required knowledge OR loss of beneficiary	Low	Med	1	Firstly, the activity can be found within the consortium. If not possible, the consortium will look for another organization with similar competences and characteristics, either subcontracting a third party.
Loss of required knowledge due to departure of key personnel	Low	High	1	ZDZW partners commit to identify and properly allocate alternative personnel should key personnel depart from the project. A plan will be set up to allow easy integration of new people in the project. The time to train added resources to work on the project will be considered staffing plan.
Unclear Requirements	Med	Med	2	Frequent meetings and workshops will be dedicated to the elicitation of requirements and clarification of the technologies applied with the initiative-taking involvement from both of end users from each pilot scenarios.
Lack of generality of identified requirements	Low	Med	2, 9	WP2 will monitor that the identified requirements are matched with the general requirement of EU companies to be focused on those that are extensive in Europe.

Inadequacy of selected technologies	Low	Med	4-6	The ZDZW Inspection Suites will be built on top of an existing solutions and adding technologies developed by some ZDZW partners in previous projects (ZDMP, i4Q, vf-OS)
Other similar solutions already present on market	Low	High	2, 3	The consortium will closely monitor the market to promptly identify competitors and envision future evolutions of the ZDZW offer to differentiate from the existing solutions.
Poor or ineffective dissemination	Low	Low	7	ZDZW will periodically review and assess the dissemination strategy considering both the level of dissemination and the target audience.
IPR problems arising during exploitation	Low	Med	8	Any IPR ownership conflicts that cannot be resolved through T3.3 and/or with the principles of the CA and GA will be managed according to the dispute resolution provision set forth in the CA.
COVID-19 pandemic situation	Low	Med	1	The measures will try to keep the business running under extraordinary conditions due to the pandemic (telework, shift work and other unusual work arrangements with a reduced workforce), including with respect to the supply of raw materials, cash stock for emergency, cash flow from banks, means of transportation and product delivery to customers. The measures will be communicated to all workers, contractors and suppliers.

CHANGE LOG

VERSION	DESCRIPTION OF CHANGE
V0.1	First table of contents provided by deliverable editor
V0.2	First version for review
V0.3	Corrections added from first reviewer
V0.4	Corrections added from second reviewer
V1.0	Submitted version