INFINITE

Aerospace composites digitally sensorized from manufacturing to end-of-life

D8.4
Evaluation framework, KPIs, Impact Assess, and Risks Management

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1. EXECUTIVE SUMMARY

Deliverable *"D8.4 – Evaluation Framework, KPIs, Impact Assessment, and Risk Management*" outlines a comprehensive and structured approach for assessing the impacts of the INFINITE project's outcomes. It also includes risk management strategies implemented by the project consortium.
This evaluation framework initially was centered around the definition and analysis of Key Performance Indicators (KPIs), which were established both during the proposal phase and further refined in Work Package 1 – Initial Requirements Definition. The KPIs defined under WP1 are documented in Deliverable D1.1 – "Report Specifications INFINITE."
These Key Performance Indicators (KPIs) are aligned with the Key Performance Areas (KPAs) defined within the project, encompassing technical, social, and environmental dimensions. However, due to the low Technology Readiness Level (TRL) of the developments and the technical challenges encountered, it has not been possible to reliably measure or assess the predefined KPIs.

As a result, a redesign of the evaluation framework became necessary. The revised approach shifts the focus from quantitative metrics to a qualitative assessment, emphasizing the progress made in scientific and technological development, integration feasibility, and the broader potential impacts of the project.

2. INTRODUCTION

2.1 OBJECTIVE OF THIS DELIVERABLE

The primary objective of Deliverable D8.4 is to establish a structured and adaptable framework for evaluating the outcomes and impacts of the INFINITE project. This includes:

- Defining an Evaluation Framework: To provide a comprehensive methodology for assessing the project's results in relation to its initial goals, particularly in light of evolving technical circumstances and constraints.

- Developing and Analyzing KPIs: To define Key Performance Indicators that align with the project's Key Performance Areas—technical, social, and environmental—and to document these KPIs as originally outlined in Deliverable D1.1.

- Adapting to Project Realities: To acknowledge the challenges posed by the low Technology Readiness Level and technical limitations, which prevented reliable quantitative measurement of KPIs, and to consequently revise the evaluation approach.

- Implementing a Qualitative Assessment: To shift the focus from strict quantitative KPI tracking to a qualitative evaluation of scientific and technological progress, integration feasibility, and anticipated long-term impacts.

- Managing Project Risks: To outline the risk management strategies applied by the project consortium, ensuring that potential issues are identified, monitored, and mitigated throughout the project lifecycle.

2.2 PROJECT OBJECTIVES

INFINITE proposes an innovation strategy focused on the development of **Next generation digital aircraft transformation in multifunctional and intelligent airframe parts**, by incorporating engineered amorphous ferromagnetic microwires within the composite integrated in the raw fabrics, to **wirelessly monitor composites manufacturing process and service life for high-performance**. The advanced quality monitoring for the manufacturing process, and during in-service conditions proposed by INFINITE has the potential to deliver a significant impact on cost reduction and safety reliability of composite components, providing a competitive advantage for European OEMs, composite manufactures and MROs.

The combination of new intelligent materials and monitoring technologies will **enable a broader spectrum of applications** in the growing area of aerospace structural composites, by providing a **sustainable technology** that improves both **processing efficiency** and **safety** during life performance.

INFINITE project defined next specific objectives at the beginning of the project:

- **<u>Objective 1 (O1)</u>: Demonstration of the capacity to integrate sensors on the composite parts.** (supported by **WP1**).
- **<u>Objective 2 (O2)</u>: To develop integrated technologies and methodologies towards next generation of composite SHM.** (supported by **WP2.)**
- **<u>Objective 3 (O3)</u>: To monitor and control the on-line manufacturing process of sensorised fabrics composites.** (supported by **WP3.)**
- **<u>Objective 4 (O4):</u> To ensure the safe and efficient composite aircraft structures maintenance and repair processes.** (supported by **WP4.)**
- **<u>Objective 5 (O5):</u> To improve sustainability of aerospace components, defining suitable end of life strategies and assessing the environmental impact of sensorised composite materials. (**supported by **WP5.)**
- **<u>Objective 6 (O6)</u>: To demonstrate and validate the project concept and solutions. Ultimately providing guidance for aircraft certification requirements**. (supported by **WP6.)**

2.3 KPIS OF INFINITE PROJECT

Previously described objectives were expected to be evaluated through the following KPIs

WP	Objectives 1	2	3	4	5	6	KPI	Target
1, 6	•	•	•	•	•	•	Guidance for SHM Requirements & Certifications	Doc.
2	•	•					Stress &Temperature detection accuracy in SHM (%)	3
2	•	•					Position and Orientation accuracy in SHM (%)	5
2	•	•					Process Rate in NCF manufacturing (m/h)	100
3	•		•				Lay-up rate in automation of NCF handling process (m/min)	50
3	•		•				Orientation accuracy in automation of NCF handling process (º)	2-3
3	•		•				Ply edge deviation in automation of NCF handling process (mm)	2
3	•		•				Wrinkles detection in automation of NCF handling process (%)	90
3	•		•				Process temperature range in preforming (º)	8
3	•		•				Process temperature range in infusion process (º)	15
3	•		•	•			Productivity increase in the whole production chain (%)	+20
3	•		•	•			Scrap reduction in the whole production chain (%)	-15
3	•		•	•			Cost reduction in the whole production chain (%)	-15
3	•		•	•			Material consumption production (%)	-15
3, 6	•		•	•			Defect identification time production chain (%)	-15
4	•			•			Overstress measurement in maintenance process (%)	60
4	•			•			Overheat measurement in maintenance process (%)	60
4				•			Reduction time to implement a bonded repair (%)	-20
4				•			Reduce of repair cure time (%)	-50
4				•			Improve quality of bonding (%)	-20
4				•			Reduce of cost and use of repair consumables (%)	-20
5					•		Re-use – Non-Aerospace re-use to prevent landfill (%)	5
5					•		Re-purpose waste preventing landfill (%)	10
5					•		Recycle EoL sensorised material (%)	60

So, based on previous data and stated in deliverable D1.1– "Report Specifications INFINITE". This project also foresaw the following specific KPIs:

2.3.1 IMPROVEMENT IN NCF MANUFACTURING. EVOLUTION OF KPIS

The KPIs related to the NCFs manufacturing process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives	KPI	Target

WP	1	2	3	4	5	6	KPI	Target
2	•	•					Process Rate in NCF manufacturing (m/h)	100
3	•		•	•			Productivity increase in the whole production chain (%)	+20
3	•		•	•			Scrap reduction in the whole production chain (%)	-15
3	•		•	•			Cost reduction in the whole production chain (%)	-15
3	•		•	•			Material consumption production (%)	-15
3, 6	•		•	•			Defect identification time production chain (%)	-15

Table 1. Evolution of KPIs in the NCFs manufacturing.

2.3.2 IMPROVEMENTS IN LAY-UP PROCESS. EVOLUTION OF KPIS

The KPIs related to the lay-up process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives						KPI	Target
	1	2	3	4	5	6		
3	•		•				Lay-up rate in automation of NCF handling process (m/min)	50
3	•		•				Orientation accuracy in automation of NCF handling process (º)	2-3
3	•		•				Ply edge deviation in automation of NCF handling process (mm)	2
3	•		•				Wrinkles detection in automation of NCF handling process (%)	90
3	•		•	•			Productivity increase in the whole production chain (%)	+20
3	•		•	•			Scrap reduction in the whole production chain (%)	-15
3	•		•	•			Cost reduction in the whole production chain (%)	-15
3	•		•	•			Material consumption production (%)	-15
3, 6	•		•	•			Defect identification time production chain (%)	-15

Table 2. Evolution of KPIs in the lamination process.

2.3.3 IMPROVEMENTS IN PREFORMING PROCESS. EVOLUTION OF KPIS

The KPIs related to the preforming process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives						KPI	Target
	1	2	3	4	5	6		
3	•		•				Orientation accuracy in automation of NCF handling process (º)	2-3
3	•		•				Ply edge deviation in automation of NCF handling process (mm)	2
3	•		•				Wrinkles detection in automation of NCF handling process (%)	90
3	•		•				Process temperature range in preforming (º)	8
3	•		•	•			Productivity increase in the whole production chain (%)	+20
3	•		•	•			Scrap reduction in the whole production chain (%)	-15
3	•		•	•			Cost reduction in the whole production chain (%)	-15
3	•		•	•			Material consumption production (%)	-15
3, 6	•		•	•			Defect identification time production chain (%)	-15

Table 3. Evolution of KPIs in preforming process.

2.3.4 IMPROVEMENTS IN THE INFUSION PROCESS. EVOLUTION OF THE KPIS

The KPIs related to the infusion process and the description of the influence of the microwires monitoring remote system on these KPIs are described below.

WP	Objectives						KPI	Target
	1	2	3	4	5	6		

3	•		•				Process temperature range in infusion process (º)	15
3	•		•	•			Productivity increase in the whole production chain (%)	+20
3	•		•	•			Scrap reduction in the whole production chain (%)	-15
3	•		•	•			Cost reduction in the whole production chain (%)	-15
3	•		•	•			Material consumption production (%)	-15
3, 6	•		•	•			Defect identification time production chain (%)	-15

Table 4. Evolution of KPIs in infusion process.

2.3.5 IMPROVEMENTS IN THE KPIS RELATED TO SHM

WP	Objectives						KPI	Target
	1	2	3	4	5	6		
1, 6	•	•	•	•	•	•	Guidance for SHM Requirements & Certifications	Doc.
2	•	•					Stress & Temperature detection accuracy in SHM (%)	3
2	•	•					Position and Orientation accuracy in SHM (%)	5

Table 5. Evolution of KPIs related to SHM.

2.3.6 IMPROVEMENTS OF KPIS RELATED TO END OF LIFE

WP	Objectives						KPI	Target
	1	2	3	4	5	6		
5					•		Re-use – Non-Aerospace re-use to prevent landfill (%)	5
5					•		Re-purpose waste preventing landfill (%)	10
5					•		Recycle EoL sensorized material (%)	60

Table 6. Evolution of KPIs related to End Of Life.

2.4 EXPECTED IMPACT

Following, the expected impacts of the INFINITE project are described:

2.4.1 HORIZON-CL5-2021-D5-01-06 TOPIC EXPECTED IMPACTS

Expected impact
INF-SHM: Development / integration of magnetic MWs and data reader.
INF-MoM: New way to monitor and control the method of manufacture.
INF-In Service: Wireless sensor technology for inspection and novel repair capability
INF: End-of-life: Sensor system recyclability /sustainability
INF- Validation and Certification: Novel material qualification and certification guidance

2.4.2 CONTRIBUTION TO EUROPEAN INDUSTRIAL COMPETITIVENESS

The INFINITE project is expected to generate a broad and transformative impact across multiple sectors, particularly within the aerospace and advanced manufacturing industries.

Its most significant influence lies in the **manufacturing of Non-Crimp Fabrics (NCFs)**, where INFINITE introduces smart, sensorized composites that incorporate wireless, real-time health monitoring systems. These innovations enhance production efficiency, quality, and safety while reducing lifecycle costs.

In the sensor industry, the project **disrupts traditional methods by eliminating the need for physical sensor connections**. Through ferromagnetic microwires (MWs) and portable wireless readers, INFINITE offers a scalable and cost-effective alternative to fiber optic sensing technologies.

INFINITE also revolutionizes composite materials design and certification, **bringing forward digital twin capabilities that simulate both manufacturing and in-service conditions**. This contributes to faster, more accurate certification, reduced design costs, and lower environmental impact.
The project significantly advances aerospace manufacturing strategies, improving automation, data interoperability, and real-time process monitoring. These enhancements support a more digital, efficient, and connected industrial ecosystem.
In terms of quality control, INFINITE's real-time monitoring drastically reduces defects and waste, especially during the high-cost lay-up phase, by replacing manual inspections with automated sensing technologies.
Regarding flight safety and efficiency, INFINITE's ability to track composite integrity from production through end-of-life improves aircraft reliability and enables predictive maintenance, reducing downtime and ensuring higher safety standards.

Finally, INFINITE addresses sustainability and recycling, exploring recyclable sensorized materials and promoting full lifecycle thinking. This benefits not just primary manufacturers, but also MRO providers, OEMs, and airlines, reinforcing circular economy principles in aerospace.

2.4.3 CONTRIBUTIONS TO EUROPEAN TECHNOLOGY PLATFORMS

INFINITE project is officially under the cluster of sister projects of HORIZON-CL5-2021-D5-01. Representatives from DIDEAROT, CAELESTIS, DOMMINO, GENEX, NEXTAIR, and INFINITE EU projects collaborate for joint dissemination activities and fostering for new technological challenges or collaboration opportunities.

2.4.4 CONTRIBUTIONS TO SOCIETAL CHALLENGES

The project is aligned with the societal challenges of Europe and wants to carry out some small contributions in the right direction in the European society.

Social challenge:

• Securing jobs keeping Europe as the global manufacturing quality leader: INFINITE improves manufacturers' ability to reduce defects and deliver products of excellent quality that meet stringent aerospace quality requirements.

• Talent acquisition for the European industry: The industrial sector faces challenges such as the digitalisation and transformation of production environments, and in these circumstances the demand for professionals with a great capacity to adapt to changes, concern for continuous learning and passion to face new challenges is naturally higher.

• Creating knowledge-intensive jobs in Europe: INFINITE research project stimulates knowledge-intensive job creation in Europe by focusing on disruptive innovative technologies based on ferromagnetic MicroWires sensors that with specific equipment (portable reader) provide relevant information of Carbon fiber components in a way that both the manufacturing processes of the Carbon Fiber and their maintenance, repair (SHM) and End of Life can be improved significantly. In addition, intensive collaboration withing INFINITE Consortium partners is expected, where industry partners, universities, and research institutions significantly improved their skills through development and training. Ensuring the workforce is equipped for emerging sectors. Moreover, the project performed clustering activities, what enhanced the opportunities to share knowledge among partners of syster projects under the same European call topic.

Another focus was pointed on trying to engage with policymakers to influence in a near future in supportive regulations and funding mechanisms.

Environment, resource efficiency and raw materials challenge: Scrap, wear, and waste represent key elements in the environmental performance of both manufacturing processes and the SHM of Aerospatiale carbon fiber components. The project's non-destructive inspection approach aims to decrease these parameters, thereby enhancing the overall environmental performance throughout the life cycle of the produced components. The potential widespread adoption of the project's outcomes by numerous manufacturers across Europe has the potential to yield significant environmental benefits.

Secure societies challenge: Ensuring the safety of critical aerospace components made from carbon fiber is paramount for European society's secure travel. The ability to continuously monitor these components throughout their lifecycle (from their manufacturing up to their end of life) guarantees that they are free from defects and operate within specified security parameters. This advanced capability not only enhances the reliability of aerospace materials but also establishes a robust system for continuous monitoring, contributing significantly to the overall safety and efficiency of air travel across Europe. By upholding stringent quality standards in the manufacturing process and ongoing performance assessments, this technology plays a pivotal role in safeguarding the aerospace industry and promoting public confidence in air travel.

2.4.5 CONTRIBUTIONS TO STANDARDS AND CERTIFICATIONS

INFINITE builds the **technical foundation**, supplies **field-proven data**, and engages in **stakeholder collaboration**, collectively supporting the development and/or improvement of **standards** and certification pathways for sensorized aerospace composites. This enables more efficient quality assurance, lifecycle tracking, and ultimately, broader industry adoption of intelligent structural materials.

2.5 RISKS MANAGEMENT

Given the high degree of innovation involved in the technologies and materials proposed in the INFINITE project, risk management is a crucial pillar within the project management. The continuous review of the risks identified in the proposal phase, the identification of new unforeseen risks and their management, through the implementation of mitigation actions and the assessment of the effectiveness of these actions in reducing risks, is essential for the project's success. This strategy ensured that any potential threats are adequately controlled, thus minimizing their impact and ensuring the achievement of the project's objectives.

Following tables present the foreseen and unforeseen risks identified and the mitigation actions adopted in the project:

Foreseen Risks

Nº	Description	WP Nº(s)	Risk Mitigation Measures
1	Development of the Compat Reader	1,2,3	Different set-ups based on transmission and reception antennas and an oscilloscope to be used to measure signals
2	Orientation and position detection	3,4	Validation activities to be defined as soon as possible to assess different morphology, dimensions and configuration
3	Carbon Fibre interference with magnetic signals	2,3,4	Developing a fully controlled signal. Modelling and simulation the signals based on the microwire network
4	Development of the sensorised NCF	2,3	Preindustrial NCF's manufacturing will not be obtained until the midline of the project. Tailored fibre placement (TFP) will be used in the first's stages of the project.
5	Intermediate layers signal interference	2,3,4	The microwires network configuration will be define by simulation and modelling of the signals
6	Signal processing: high-rate outputs manufacture process	2,3,4	Calibration and early validation activities to optimise sensors, reader and interpretation of results is critical
7	Incompatibility with current signals of aircraft	4,5	Certification strategy will investigate this issue. Input for EASA and IAB
8	Availability of required data to perform SHM	4	Engagement with other WPs from beginning
9	Quality of the data – availability of structural degradation signature in the data	4	Well planned design of experiments during data generation phase
10	TRL of Algorithm	4	SOA analysis and Innovation
11	Compatibility between resin, binders and microwires in the composite part.	1,2,3	To include specifications in WP1. Type of resin and binder for the development of the wires and all
12	The main pyrolysis equipment intended to be used to test the thermochemical treatment to recycle	5	Preindustrial NCF´s manufacturing will not be obtained until the midline of the project.
13	Lack of primary information to perform the environmental and economic life cycle assessments	5	Use and continuously update LCA/LCC databases as the Ecoinvent or GaBi databases.

Table 2-7 Foreseen Risks management.

Unforeseen Risks

Nº	Description	WP Nº(s)	Risk Mitigation Measures
1	One of the partners cannot fulfil its obligations in the project	1,2,3	Carefully revision of the activities of each partners in order to progress properly
2	Necessity of portable reader system to advance in the monitoring of MoM, SHM maintenance and EoL activities.	3,4,5	Accelerate the construction of the first versions of the portable reading system

Table 2-8 Unforeseen Risks management.

3. EVALUATION FRAMEWORK

The purpose of this framework is to support the effective implementation and success of the project by addressing three main goals. First, it aims to evaluate the scientific, technological, economic, societal, and environmental impacts generated by the project. Second, it ensures the early identification and continuous monitoring of potential risks that could affect progress. Finally, the framework is designed to guide corrective actions when necessary, helping to increase the chances of achieving the expected outcomes and long-term impacts defined in the project objectives.

3.1 STATE OF THE ART

The use of **Key Performance Indicators (KPIs)** as a core component of performance evaluation frameworks has been widely adopted across industries and disciplines. The approach is supported by both academic research and practical methodologies, emphasizing its effectiveness in aligning operations with strategic goals, enhancing accountability, and facilitating data-driven decision-making.
Several models and frameworks in the literature provide a foundation for KPI-based evaluation:

1. **Balanced Scorecard**
   The Balanced Scorecard remains one of the most influential frameworks for performance management. It integrates financial and non-financial KPIs across four perspectives—financial, customer, internal processes, and learning & growth—highlighting the importance of aligning KPIs with long-term strategy. It supports both strategic alignment and continuous feedback, which are essential for effective evaluation.
   Reference: Kaplan, R. S., and D. P. Norton. 1992. The Balanced Scorecard: Measures that drive performance. HarvardBusiness Review (January-February): 71-79
2. **SMART Criteria for KPI Design**
   Widely adopted in both academic and professional settings, the SMART criteria—Specific, Measurable, Achievable, Relevant, and Time-bound—are used to ensure that KPIs are meaningful and actionable. Research has shown that SMART-aligned KPIs lead to better clarity and goal-setting outcomes.
   Reference: Doran, G. T. (1981) 'There's a S.M.A.R.T way to write management's goals and objectives', Management Review, 70(11), pp. 35-36.
3. **Performance Prism**
   This framework expands the traditional view of performance measurement by including stakeholder satisfaction and contribution as central evaluation criteria. It reinforces the idea that KPIs must be designed to capture multi-dimensional value creation across stakeholders.
   Reference: A. Neely, C. Adams and M. Kennerley, (2002) "The Performance Prism: The Scorecard for Measuring and Managing Success," Pearson Education Limited.
4. **Data-Driven Decision Making (DDDM)**
   Contemporary organizational studies emphasize the value of DDDM, where KPI analysis plays a central role. This approach promotes continuous monitoring, predictive insights, and agile response to operational issues—key principles supported by KPI-based frameworks.
   Reference: Provost, F. and Fawcett, T., 2013. Data science and its relationship to big data and data-driven decision making. Big data, 1(1), pp.51-59.
5. **ISO Standards on Performance Evaluation (e.g., ISO 9001:2015)**
   International standards such as ISO 9001 stress the need for systematic measurement and performance evaluation, often through KPIs. These standards recommend setting measurable objectives, monitoring results, and using findings for continuous improvement.
6. **Digital Transformation and KPI Dashboards**
   Modern software tools and dashboards (e.g., Power BI, Tableau, Google Data Studio) have further strengthened KPI frameworks by enabling real-time monitoring and visualization. This enhances transparency, stakeholder communication, and rapid decision-making, as highlighted in digital performance management literature.

3.2 QUALITATIVE ASSESSMENT FRAMEWORK FOR LOW-TRL

This evaluation framework has been designed to suit the early-stage (low TRL) nature of the INFINITE EU project. Traditional KPI-based approaches are not suitable at this stage due to limited operational validation. Instead, this qualitative framework serves three main strategic purposes:

1. Impact Assessment: Evaluate the project's contributions across scientific, technological, economic, societal, and environmental domains.

2. Risk Monitoring: Ensure early identification and continuous monitoring of critical risks that may impede progress.
3. Corrective Action Guidance: Provide structured insights to support decision-making and adapt the project trajectory when needed, thereby enhancing the likelihood of achieving expected outcomes and long-term impacts.

3.2.1 FRAMEWORK STRUCTURE AND EVALUATION AXES

The framework is structured around five thematic axes aligned with the state of the art in early-stage R&D and impact-oriented innovation management.

- Scientific and Technological Advancement
  - Novelty of the approach (e.g., domain-wall propagation, GMI effect)
  - Technical feasibility demonstrated in lab conditions
  - Benchmarking against existing academic or experimental results

- Integration Readiness and Prototype Development
  - Maturity of the prototype (form factor, stability)
  - Feasibility
  - Development and functional testing

- Impact Potential
  - Scientific Impact: Peer-reviewed dissemination and knowledge generation
  - Technological Impact: Positioning for higher TRLs and future exploitation
  - Economic Impact: Alignment with market trends (e.g., SHM systems, Industry 4.0)
  - Societal Impact: Contribution to structural safety, aerospace monitoring, and smart infrastructure
  - Environmental Impact: Potential for material/resource efficiency and lifecycle benefits

- Risk Assessment and Mitigation
  - Identification of technical and operational risks (e.g., sensor fragility, signal distortion, integration failure)
  - Risk categorization by likelihood and impact
  - Monitoring mechanisms (e.g., lab test logs, partner feedback, technical review checkpoints)

- Adaptive Management and Corrective Action Readiness
  - Responsiveness to setbacks (e.g., redesign iterations, test plan adjustments)
  - Use of evaluation insights to inform project steering
  - Involvement of partners in periodic reviews to refine development paths

3.2.2 EVALUATION METHODOLOGY

To ensure a structured, comprehensive, and meaningful analysis of the INFINITE project's progress and impact, the evaluation methodology is designed around a qualitative, multi-dimensional framework. This framework enables assessment across key impact axes (scientific, technological, economic, societal, and environmental) despite the current limitations of quantitative KPIs due to the project's low Technology Readiness Level (TRL).

Each axis is assessed using the following core components:

- **Descriptive Narratives:** A structured narrative approach is used to capture detailed, context-rich information about project activities, outcomes, and lessons learned.
- **Evaluation Level:** For each dimension, the current maturity or development stage is described based on TRL or equivalent qualitative criteria. This helps position achievements within the broader innovation lifecycle and clarify how far the outcomes are from practical implementation or market readiness.
- **Key Achievements:** This includes a concise summary of the most important results and breakthroughs obtained during the reporting period. Emphasis is placed on scientific and technological innovation, integration feasibility, system performance, knowledge generation, and collaboration outcomes.

- **Remaining Challenges:** Each axis includes a forward-looking reflection on unresolved issues, technological barriers, coordination needs, or external dependencies. Identifying these challenges provides the foundation for targeted corrective actions and future work planning.

Additionally, the evaluation process is iterative and dynamic, allowing periodic refinement as the project evolves. This ensures that the framework remains responsive to project changes and continues to support decision-making, risk mitigation, and impact maximisation throughout the project lifecycle.

4. FINAL EVALUATION

The implementation of an evaluation framework based on the assessment of Key Performance Indicators (KPIs) has proven unfeasible in the context of the INFINITE EU project. This limitation is primarily due to the low Technology Readiness Level (TRL) of the core innovations under development. At this early stage, many of the predefined KPIs—typically reliant on mature, validated technologies and quantifiable outcomes—could not be meaningfully measured or applied.

Consequently, it has not been possible to assess progress using the original set of KPIs, which were designed under assumptions of a higher TRL and more advanced stages of technical maturity. In response to this challenge, the evaluation framework was adapted to reflect the actual stage of technological development.

Instead of focusing on quantitative performance indicators, the revised framework emphasizes **qualitative improvements** and **technological breakthroughs** achieved during the course of the project. Notably, this includes the successful development of **ferromagnetic microwire sensors** and a **portable reader device** designed to monitor the signals emitted by these sensors. These advancements represent critical steps forward in the project's innovation pathway, providing foundational insights and technical solutions that pave the way for future KPI-based assessments as the technology matures.

This qualitative-focused approach ensures that the evaluation remains meaningful, proportionate to the current TRL, and aligned with the project's iterative R&D trajectory. It also highlights the innovation potential and the added value of the research activities carried out within INFINITE, despite the current limitations in quantitative validation.

4.1 QUALITATIVE EVALUATION OF THE INFINITE PROJECT

4.1.1 SCIENTIFIC AND TECHNOLOGICAL ADVANCEMENT

Significant progress has been made in the development of the sensing system based on ferromagnetic microwires (MWs). New MWs have been manufactured with improved magnetic properties and mechanical behaviour, enabled by optimized alloy composition and adjusted diameters, specifically designed to perform reliably in carbon-saturated environments like aerospace composites. These advances facilitate easier incorporation into carbon fibre fabrics through automation. Improvements were also made in the lab setup, including new coils, amplifiers, and detection systems, to enhance the identification and acquisition of MW signals. The orientation and stacking configuration of fibres within the composites were also optimized in response to MW presence, providing new approaches to preform design.

- Evaluation Level: Lab demonstration with system-level adaptation (TRL 3–4)
- Key Achievements: New MW materials and geometries, upgraded signal detection setup, preform configuration strategies
- Remaining Challenges: System robustness in full composite prototypes; long-term signal reproducibility

4.1.2 INTEGRATION READINESS AND PROTOTYPE DEVELOPMENT

A simplified portable reader system was developed to ensure usability across all stages of the composite lifecycle, enabling monitoring from production to end-of-life. This reader is tailored to function across partner facilities throughout the value chain. New methods for sensor integration into Non-Crimp Fabrics (NCFs) were implemented, including MW insertion between ±45° carbon fibre layers using a guiding system, and development of DFP tapes embedding MWs at 0°. Simulation models were also developed to analyse stress/strain interactions with embedded MWs.

- Evaluation Level: System prototyping; contextualized integration trials (TRL 3–4)
- Key Achievements: Reader system portability, NCF sensor integration strategies, simulation-informed design
- Remaining Challenges: Field validation and performance consistency in operational scenarios

4.1.3 IMPACT POTENTIAL

While quantitative impact assessment is limited at this stage, the project demonstrates strong long-term potential across several dimensions:

- Scientific Impact: Novel SHM techniques using GMI response in embedded MWs, supported by simulation and experimental validation, demonstrate high innovation.
- Economic Impact: Influence on the NCF manufacturing and sensor industries, with disruptive wireless sensor technologies reshaping composite design, quality control, and certification.
- Societal Impact: Project outcomes support improved safety, manufacturing efficiency, and reduced lifecycle costs in aerospace and related sectors. New knowledge-intensive roles are expected to emerge, strengthening Europe's industrial base.
- Environmental Impact: A preliminary life cycle assessment (LCA) was conducted. Introduction of recycled carbon fibre layers and longer-lasting composites point to better resource use and sustainability.
- Wider Societal Implications: Job security, talent acquisition, and enhanced air travel safety in Europe.

The following table presents General impacts and risks matrix evaluation:

Axis	Outcome	Indicators of Progress	Risks Identified	Adaptive Measures
Scientific	Knowledge creation, publications	Presentations, citations, lab results	Lack of reproducibility	Increase trials, partner review
Technological	Functional prototype, sensor integration	Lab performance, signal traceability	Device, system or method instability	Redesign iterations
Economic	TRL progression, innovation positioning	TRL tracking, IP interest	Market misalignment	Reassess value proposition
Societal	Awareness, stakeholder relevance	SHM use cases, safety benefits	Low stakeholder uptake	Engage with end-users early
Environmental	Resource savings, lifecycle impact	Material use data, recyclability	Integration complexity	Evaluate alternative materials

- Evaluation Level: High potential for future impact; systemic innovation across industry and policy
- Key Achievements: Sector-wide influence, environmental modelling, societal and economic impact foresight
- Remaining Challenges: Validation of environmental claims; long-term adoption by aerospace stakeholders

4.1.3.1 ALIGNMENT WITH HORIZON-CL5-2021-D5-01-06 TOPIC EXPECTED IMPACTS

The INFINITE project directly addresses the expected impacts of the Horizon Europe call HORIZON-CL5-2021-D5-01-06 by advancing breakthrough technologies for the **integration of multifunctional sensing capabilities** into aerospace-grade composite materials. It demonstrates novel **non-intrusive, embedded, wireless structural health monitoring (SHM) solutions** using ferromagnetic microwires, aligning with the topic's goal of improving the **safety, performance, and sustainability of advanced materials and structures**. The project contributes to improving **lifecycle monitoring**, enabling better **predictive maintenance** and reducing material waste and maintenance-related emissions, thus supporting the transition toward **greener and safer aerospace technologies**.

4.1.3.2 CONTRIBUTION TO EUROPEAN INDUSTRIAL COMPETITIVENESS

INFINITE strengthens European industrial competitiveness by developing **disruptive sensing solutions** tailored to high-performance composite manufacturing, a strategic sector in European aerospace and transportation industries. The project enables:

- **Automation-ready sensing technologies** that facilitate smart factories and reduce reliance on manual inspection.
- New manufacturing methods for **Non-Crimp Fabric (NCF) composites** embedded with sensors, enhancing material traceability and quality assurance.
- Early involvement of European SMEs and industrial stakeholders, facilitating **technology transfer** and **market uptake** in high-value applications such as aviation, automotive, and wind energy. Overall, INFINITE helps maintain Europe's leadership in advanced materials innovation while fostering new **knowledge-intensive jobs and value chains**.

4.1.3.3 CONTRIBUTIONS TO EUROPEAN TECHNOLOGY PLATFORMS

INFINITE project collaborated with sister projects through cluster activities.

4.1.3.4 CONTRIBUTIONS TO SOCIETAL CHALLENGES

The project addresses several key societal challenges:

- **Environmental sustainability:** by enabling the monitoring of composites manufacturing processes in real time and thus reducing the production of defective parts and through predictive maintenance and reducing the environmental footprint of composite structures via extended service life and reduced downtime.
- **Job creation and skills development:** through the promotion of cutting-edge sensing technologies, creating opportunities for high-skilled employment in materials science, data analytics, and smart manufacturing.
- **Safety and resilience:** via early damage detection and real-time monitoring, contributing to safer transport systems and infrastructure.
- **Circular economy:** by introducing new techniques for the reuse and integration of **recycled carbon fibre** layers into high-value components.
  These outcomes support Europe's Green Deal objectives and the broader vision of a climate-neutral, resource-efficient economy.

4.1.3.5 CONTRIBUTIONS TO STANDARDS AND CERTIFICATIONS

INFINITE lays the groundwork for integrating SHM technologies into regulatory frameworks, thereby accelerating industrial adoption and market access.

4.1.4 RISK ASSESSMENT AND MITIGATION

Risk management has played a central role in project execution. The unexpected withdrawal of two consortium partners (DANOBAT and RECICLALIA) required swift reallocation of tasks and budget adjustments. Technical risks related to sensor signal instability were actively monitored. Of the 13 predefined risks, 11 were mitigated, and two unforeseen risks were addressed through contingency planning.

- Evaluation Level: High effectiveness in risk control and operational continuity
- Key Achievements: Minimal disruption to timeline; responsive mitigation strategies
- Remaining Challenges: Continued monitoring of unresolved technical integration risks

4.1.5 ADAPTIVE MANAGEMENT AND CORRECTIVE ACTIONS

The project demonstrated strong adaptive capacity, with key revisions implemented to preserve alignment with the Description of Action (DoA). The evaluation framework was modified to accommodate the limitations of a KPI-based assessment at low TRL, shifting to a qualitative approach. Project coordination remained robust, enabling timely delivery of critical outputs despite significant internal changes.

- Evaluation Level: High adaptability; well-managed governance under changing conditions
- Key Achievements: Redesign of evaluation methodology; successful delivery of key deliverables
- Remaining Challenges: Sustaining partner engagement and progress toward system-level validation

5. CONCLUSIONS

This deliverable has established a robust and adaptive methodology to monitor the progress, evaluate the outcomes, and manage the risks associated with the INFINITE project. Given the low Technology Readiness Level (TRL) at the project's inception, it became evident that many of the initially defined quantitative Key Performance Indicators (KPIs) were not yet applicable or measurable within the current technical context. As a result, a redesigned evaluation framework was developed, emphasizing a qualitative, narrative-driven approach to track advancements and identify impacts across scientific, technological, economic, societal, and environmental dimensions.

This revised framework has proven effective in capturing the project's significant achievements, such as the development of advanced ferromagnetic microwire sensors, their integration into aerospace-grade composites, the creation of a portable reader system, and the implementation of simulation-based and machine learning-driven SHM methodologies. These milestones, although at early TRL stages, lay a solid foundation for future validation and upscaling activities.

In parallel, the deliverable outlines a proactive risk management strategy. Thirteen key risks were initially identified, of which eleven have been successfully mitigated. Additionally, two unforeseen risks were identified and effectively addressed. This demonstrates the consortium's strong capacity for early detection and agile response, ensuring continued alignment with project objectives and timelines.

Moreover, the evaluation framework supports continuous feedback loops, guiding corrective measures when necessary and fostering alignment with long-term impacts as defined in the project Description of Action (DoA). The framework not only supports accountability and transparency but also encourages informed decision-making for subsequent technical and strategic steps.