Ref. Ares(2026)4476237 - 30/04/2026

NANO—S—MART®

Progress Report 1

Deliverable 1.4

Date: 30/04/2026

Funded by
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Project Technical References

Project: Unlocking the effect of residual elements via the NANOengineering of Sustainable MARTensitic steels	
Project number	101178431
Project acronym	NANO-S-MART
Call	HORIZON-CL4-2024-TWIN-TRANSITION-01
Topic	HORIZON-CL4-2024-TWIN-TRANSITION-01-46
Type of action	HORIZON Research and Innovation Actions
Project staring date	01/11/2024
Project duration	48 months

[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Deliverable No.	D1.4
Deliverable title	Progress Report 1
Work Package	1
Task	1.1 & 1.2
Lead beneficiary	CEIT
Contributing beneficiary(ies)	CEIT
Due date of deliverable	30/04/2026
Actual submission date	30/04/2026

Document History

Version	Date	Change	Author
1.0	20/04/2026	First draft version	Unai Mayo (Ceit)
1.1	29/04/2026	Updated version	Unai Mayo (Ceit)
1.2	30/04/2026	Final version	Pello Uranga (Ceit)

EXECUTIVE SUMMARY

This deliverable D1.4, presents the public progress report corresponding to the first reporting period of the NANO-S-MART project. It provides an overview of the project implementation, highlighting progress achieved with respect to the project objectives, work plan, and key activities carried out during the reporting period.

During this first period, the project progressed in line with the DoA, with effective coordination among consortium partners and timely execution of planned tasks. Major technical activities were successfully initiated across the core work packages, including material production, hot processability assessment, nano - mechanical investigation, and modelling. Several deliverables were completed as scheduled, where the detailed results of the investigation were written.

Overall, the results from the first reporting period show that the project is progressing as planned, providing a solid technical and organizational basis for the upcoming phases and the successful achievement of the NANO-S-MART objectives.

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ABBREVIATIONS AND ACRONYMS

Abbreviations / Acronyms	Description
Ref	Reference
Cu	Copper
Sn	Tin
Sb	Antimony
As	Arsenic
P	Phosphorus
WP	Work Package
DQ	Direct quenched
RAQ	Re-austenitised and quenched

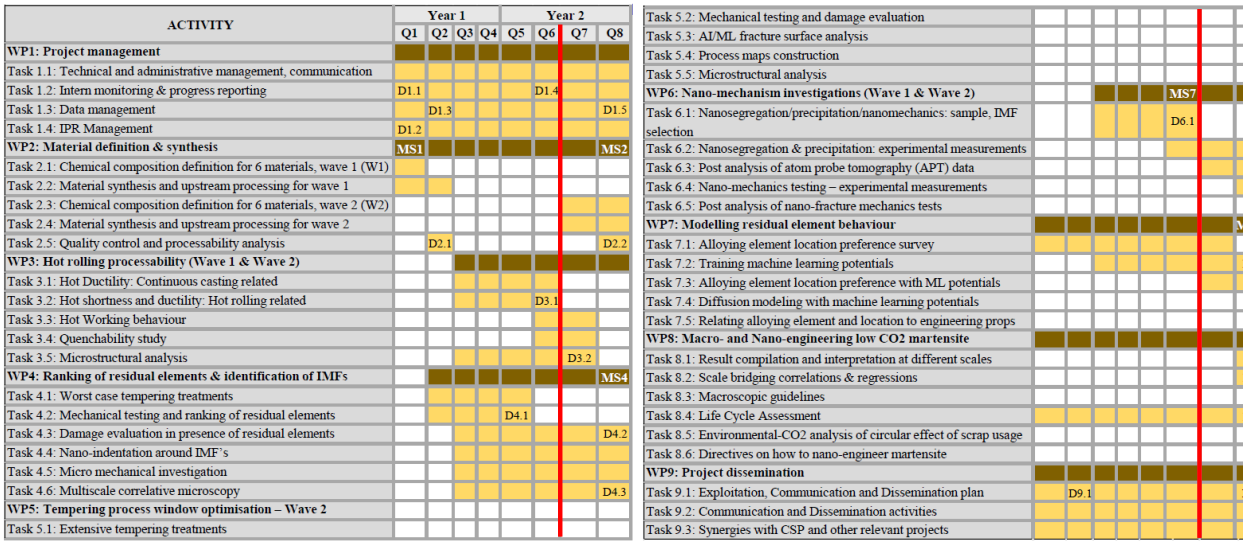
1 WP1. Project management

During the first reporting period, WP1 activities focused on ensuring the effective management, coordination, and monitoring of the NANO-S-MART project in line with the objectives defined in the DoA. Overall implementation progressed according to plan, with project activities advancing within the agreed timeline.

Project progress was continuously monitored against the project chronogram (see Table 1). By the end of the first reporting period (30/04/2026), most work packages were active, with activity levels evolving as expected. Several deliverables were successfully completed, involving contributions from nearly all WPs, demonstrating effective coordination across the consortium and confirming alignment with the planned project schedule.

Table 1. Chronogram for the first and second year.

Chronogram first & second year



ACTIVITY	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
WP1: Project management								
Task 1.1: Technical and administrative management, communication								
Task 1.2: Intern monitoring & progress reporting	D1.1					D1.4		
Task 1.3: Data management		D1.3						D1.5
Task 1.4: IPR Management	D1.2							
WP2: Material definition & synthesis	MS1							MS2
Task 2.1: Chemical composition definition for 6 materials, wave 1 (W1)								
Task 2.2: Material synthesis and upstream processing for wave 1								
Task 2.3: Chemical composition definition for 6 materials, wave 2 (W2)								
Task 2.4: Material synthesis and upstream processing for wave 2								
Task 2.5: Quality control and processability analysis		D2.1						D2.2
WP3: Hot rolling processability (Wave 1 & Wave 2)								
Task 3.1: Hot Ductility: Continuous casting related								
Task 3.2: Hot shortness and ductility: Hot rolling related						D3.1		
Task 3.3: Hot Working behaviour								
Task 3.4: Quenchability study								
Task 3.5: Microstructural analysis							D3.2	
WP4: Ranking of residual elements & identification of IMFs								MS4
Task 4.1: Worst case tempering treatments								
Task 4.2: Mechanical testing and ranking of residual elements					D4.1			
Task 4.3: Damage evaluation in presence of residual elements								D4.2
Task 4.4: Nano-indentation around IMF's								
Task 4.5: Micro mechanical investigation								
Task 4.6: Multiscale correlative microscopy								D4.3
WP5: Tempering process window optimisation – Wave 2								
Task 5.1: Extensive tempering treatments								
Task 5.2: Mechanical testing and damage evaluation								
Task 5.3: AI/ML fracture surface analysis								
Task 5.4: Process maps construction								
Task 5.5: Microstructural analysis								
WP6: Nano-mechanism investigations (Wave 1 & Wave 2)							MS7	
Task 6.1: Nanosegregation/precipitation/nanomechanics: sample, IMF selection							D6.1	
Task 6.2: Nanosegregation & precipitation: experimental measurements								
Task 6.3: Post analysis of atom probe tomography (APT) data								
Task 6.4: Nano-mechanics testing – experimental measurements								
Task 6.5: Post analysis of nano-fracture mechanics tests								
WP7: Modelling residual element behaviour								
Task 7.1: Alloying element location preference survey								
Task 7.2: Training machine learning potentials								
Task 7.3: Alloying element location preference with ML potentials								
Task 7.4: Diffusion modeling with machine learning potentials								
Task 7.5: Relating alloying element and location to engineering props								
WP8: Macro- and Nano-engineering low CO2 martensite								
Task 8.1: Result compilation and interpretation at different scales								
Task 8.2: Scale bridging correlations & regressions								
Task 8.3: Macroscopic guidelines								
Task 8.4: Life Cycle Assessment								
Task 8.5: Environmental-CO2 analysis of circular effect of scrap usage								
Task 8.6: Directives on how to nano-engineer martensite								
WP9: Project dissemination								
Task 9.1: Exploitation, Communication and Dissemination plan		D9.1						
Task 9.2: Communication and Dissemination activities								
Task 9.3: Synergies with CSP and other relevant projects								

Consortium coordination was ensured through regular email exchanges and monthly online progress meetings, which enabled continuous monitoring of technical and administrative activities, and early identification of potential risks. The kick-off meeting was held at CEIT (San Sebastián, Spain) on 4 November 2024, with all partners participating either in person or remotely. The Project Officer, Dimos Paraskevas, joined remotely and provided guidance on project implementation. In addition, the first Annual Project Meeting took place on 5 March 2026 in Ghent, hosted by OCAS NV and Ghent University. This in- person meeting supported detailed technical discussions, strengthened collaboration among partners, and enabled agreement on upcoming milestones, deliverables, and preparation of the first periodic report.

WP1 also ensured effective communication with the European Commission and compliance with reporting obligations. All technical deliverables due within the reporting period were prepared and uploaded in accordance. A deviation related to the confidentiality status of certain deliverables was identified early and managed transparently. Due to a human error during proposal preparation, several confidential deliverables had been incorrectly classified as public. An official amendment was therefore requested and approved, allowing Deliverables D1.2 and D1.3 to be uploaded once their status was corrected to “sensitive”.

In line with WP1 objectives related to data and intellectual property management, the first version of the Data Management Plan (DMP) was prepared and submitted as Deliverable D1.3. The DMP defines the data life cycle for all data generated within the project, including procedures for data handling, storage, access and dissemination. It will be updated as the project progresses. In parallel, the first version of the Intellectual Property Rights (IPR) Management Plan was submitted as Deliverable D1.2. This document establishes the governance framework for IPR management within the consortium, addressing ownership, protection of results, access rights, confidentiality, and exploitation provisions, and introducing procedures for the identification and management of Key and Secondary Exploitable Results.

Overall, WP1 activities during the first reporting period were implemented as planned and supported the achievement of project objectives. The project is progressing in line with the DoA in terms of timing, coordination, and quality.

2 WP2. Material definition & upstream synthesis

In WP2, Wave-1 materials were defined with chemical compositions based on a C-Mn-Si-B reference. In addition to the reference material, five alloys containing added residual elements (Cu, Sn, Sb, As, and P) were designed, resulting in a total of six different compositions. The selected residual element levels were defined based on industrial relevance and potential scrap evolution scenarios. The final chemical compositions showed good agreement with the defined targets.

All produced materials, from cast blocks to hot-rolled plates, were successfully processed under identical conditions and according to the planned schedule. Visual inspection did not reveal any cracking or detrimental structural defects. Detailed information on chemical composition and processing conditions is provided in Deliverable 2.1.

For each composition, as-cast 12 mm thick plates and hot-rolled plus direct-quenched (DQ) 20 mm thick plates were shipped to CEIT for hot-rolling processability testing (WP3). For all material chemistries, 6 mm thick plates were hot-rolled and quenched following either DQ or DQ + RAQ (re-austenitizing + quenching) conditions. These 6 mm thick plates are available for further investigation in the as-quenched and tempered conditions for the ranking of residual elements and identification of impacted microstructure features (IMFs) (WP4) and for nano-characterization (WP6).

An overview of the materials produced for Wave-1 is provided in Table 2.

Table 2. Target compositions of "Wave-1" materials (values in wt. %).

	C	Mn	Si	B	Cu	Sn	Sb	As	P
Reference	0.2	iso	iso	iso					
Cu	0.2	iso	iso	iso	0.2				
Sn	0.2	iso	iso	iso		0.07			
Sb	0.2	iso	iso	iso			0.04		
As	0.2	iso	iso	iso				0.04	
P	0.2	iso	iso	iso					0.02

Based on the experimental ranking of residual elements obtained in WP4, a second wave of six materials will be processed, including:

- Different levels of a single residual element
- Combination of residual elements
- Intentional alloying with a 3rd element

A more detailed composition table will be defined in Task 2.3, starting on May 2026.

3 WP3. Hot rolling processability

During the first reporting period, significant experimental work was carried out within WP3 to assess the hot processability of Wave-1 materials. All tasks defined within WP3 were initiated, and substantial experimental work was carried out on the full set of six Wave-1 material chemistries.

The hot ductility behaviour of the materials was evaluated under conditions representative of continuous casting, using thermomechanical testing designed to reproduce industrial thermal and deformation conditions. The applied methodology enabled the characterisation of ductility trends across the temperature range relevant for cracking susceptibility during casting, providing an initial comparative of material behaviour under critical conditions. The evaluated materials showed comparable hot ductility behaviour, with stable performance at high temperatures and a reduction in ductility over an intermediate temperature range, relevant for industrial processing. The microstructural characterization of fracture surfaces confirm that the ductility drop observed close to the Ae3 temperature is primarily attributed to the formation of a thin ferrite film along the austenite grain boundaries. Differences among compositions were observed in the severity of this ductility reduction, indicating a measurable influence of residual elements. These trends are consistent with known microstructural effects occurring during phase transformation and high-temperature deformation [1-4]. Further details on the experimental setup, testing conditions, and results are provided in Deliverable D3.1.

In parallel, the hot-rolling-related deformation behaviour of the materials was investigated using complementary experimental tests designed to reproduce industrial hot-rolling scenarios. The combined use of different deformation modes (torsion and bending) enabled the identification of potential sensitivity to hot-shortness related phenomena under severe processing conditions. Detailed descriptions of the experimental setup, testing conditions and results are reported in the dedicated confidential technical deliverable (Deliverable D3.1).

The hot-working behaviour of the Wave-1 materials was further studied through thermomechanical testing designed to define key process window parameters relevant for rolling operations. These experiments enabled assessment of recrystallisation behaviour and the identification of characteristic temperature ranges governing austenite softening and transformation. The results provide a basis for comparing the influence of residual elements on hot-working response and for guiding subsequent processing strategies.

Initial quenchability investigations were also performed using controlled continuous-cooling experiments by using dilatometry. These tests allowed a first evaluation of phase-transformation behaviour during cooling and provided insight into the influence of residual elements on transformation kinetics. Further experiments are planned in the coming months to complete the continuous cooling transformation (CCT) diagrams for different austenite conditions and for the DQ and RAQ processing routes.

Microstructural characterisation supported all experimental activities, using optical and electron microscopy to analyse representative samples after thermomechanical testing. This work enabled correlation between microstructural features and observed macroscopic behaviour and will continue alongside ongoing investigations. Overall, WP3 progressed in line with the objectives defined in the Description of Action. Substantial experimental data have been generated for the Wave-1 materials, providing insight into the effect of residual elements on hot processability and hot working behaviour, and enabling the definition of robust processing windows.

4 WP4. Ranking of residual elements and identification of IMFs

In the first reporting period, WP4 focused on the systematic evaluation of the influence of residual elements on the mechanical behaviour of the Wave-1 materials across the macro-, micro-, and nano-scales. Activities progressed in line with the objectives defined in the DoA and resulted in a comprehensive experimental dataset supporting a first positioning of residual elements with respect to their impact on strength, ductility, and toughness. As a first step, all twelve Wave-1 materials corresponding to six chemical compositions processed via two quenching routes (DQ, and RAQ) were subjected to a severe "worst-case" tempering treatment.

This was followed by room temperature tensile testing and Charpy impact testing at multiple temperatures to evaluate macroscopic mechanical behaviour. Mechanical testing was conducted on both as-quenched and tempered conditions, enabling a comparative assessment of the combined effects of chemistry, processing route, and heat-treatment on the macroscopic properties. The results confirmed that tempering leads to marked changes in yield strength, tensile strength, elongation, and toughness compared to the as-quenched state. Clear differences were observed between the DQ and RAQ processing routes, highlighting the critical role of processing history in determining the mechanical behaviour of steels containing residual elements. While all residual element containing materials exhibited deviations from the reference composition, no universal ranking could be established. Instead, the influence of residual elements was found to depend strongly on the interaction between alloy chemistry, processing route, and heat-treatment condition. In particular, toughness showed a higher sensitivity to residual elements and processing history than tensile strength or ductility, especially at reduced testing temperatures. All detailed experimental procedures and results concerning macroscopic analyses are reported in the dedicated confidential deliverable (Deliverable D4.1).

In parallel, published literature data were reviewed to contextualise the experimental findings and to compare observed trends with previously reported behaviour. This comparison indicated that discrepancies in testing methodologies and thermomechanical histories between literature data and the present work do not allow a direct, one to one ranking of residual elements. These observations confirm that the impact of residual elements on mechanical properties cannot be generalised without considering both processing conditions and residual element content.

To support the interpretation of the macroscopic test results, initial advanced micro- and nano-scale characterisations were initiated. High-resolution techniques, including nano-indentation mapping and micromechanical testing, were applied to probe local mechanical behaviour in the vicinity of relevant microstructural features. The nano-indentation measurements indicated that hardness is only weakly affected by the presence of residual elements, in agreement with trends observed at the macroscopic tensile tests. Micromechanical experiments further showed a pronounced reduction in yield strength after tempering across all investigated conditions, while the influence of residual elements on local yield behaviour becomes more apparent in the tempered state for selected compositions. These investigations provided first insights into the relationship between residual element additions, processing route, and the development of impacted microstructural features (IMFs).

Additionally, complementary multiscale microstructural characterisation was initiated with the objective of rationalising the origins of IMFs. Field-emission scanning electron microscopy (FEG-SEM) combined with electron backscatter diffraction (EBSD) was applied to analyse the microstructure of Wave-1 materials in quenched and tempered conditions. These analyses revealed composition and processing dependent variations in martensitic and prior austenite grain structures. The addition of several residual elements led to measurable changes in martensitic structure morphology and prior austenite grain size. After tempering, the martensitic grain size in the reference condition decreased, whereas residual element containing materials exhibited a tendency toward microstructural coarsening, with variations depending on the specific element and processing route. Changes in reconstructed prior austenite grain structures under tempering conditions further highlighted the sensitivity of austenite stability to both chemistry and heat treatment. These microstructural observations motivated the selection of site-specific regions of interest for higher resolution investigations. Accordingly, representative prior austenite grain boundaries and martensitic interfaces were identified and prepared for subsequent atom probe tomography (APT).

In summary, WP4 has successfully met its primary objectives for the first reporting period. A complete macro- mechanical dataset has been generated for all Wave-1 materials and a first processing dependent ranking of residual elements has been established (see Deliverable 4.1). Additionally, advanced micro- and nano-scale investigations have been initiated to identify the impacted microstructural features (IMFs). This work provides a solid foundation for subsequent WP4 activities, which will focus on deepening the understanding of impacted microstructural features (IMFs) and associated deformation and fracture pathways.

5 WP6. Nano-mechanism investigations

During the first reporting period, WP6 activities focused on initiating nano-scale investigations to understand how residual elements interact with key microstructural features and how these interactions influence mechanical behaviour. Work progressed in line with the DoA, following a selective approach reflecting the resource intensive nature of the applied techniques, as reported in Deliverable 6.1. The primary objective of WP6 is to investigate the role of nano-segregation and precipitation at impacted microstructural features (IMFs). To this end, a systematic sample and IMF selection strategy was first established for Wave-1 materials. This selection was based on results from WP4, and inputs form WP3 and WP7, ensuring that nano-scale investigations target the most relevant conditions. The selection procedure and scope are documented in Deliverable D6.1.

Building on this selection, nano-scale characterisation was initiated using atom probe tomography (APT) as the primary technique, complemented by correlative microscopy. Site-specific specimen preparation was performed using focused ion beam (FIB) lift-out methods to ensure precise targeting of relevant microstructural interfaces.

The first nano-scale results demonstrate clear differences in segregation behaviour among residual elements at martensitic interfaces. Correlation of nano-scale segregation behaviour with available tensile data from WP4 indicates that interfacial chemistry plays a key role in determining local interfacial cohesion and, consequently, bulk yield behaviour. This confirms that residual element effects on mechanical performance are largely governed by their redistribution at IMFs rather than by homogeneous solid-solution strengthening.

6 WP7. Modelling residual element behaviour

WP7 focuses on understanding and predicting the behaviour of residual and alloying elements in martensitic steels using computational approaches. During the first reporting period, the goal was to survey preferential locations of residual elements before and after the martensitic transformation at the prior austenite grain boundaries. By surveying the preferential positions, it provides insight into both locations of the residual elements at the time of quenching, and can offer a pathway for the residual elements when diffusing during the tempering process. To determine the preferential locations, the segregation energy is being calculated for the residual elements around multiple coincidence site lattice (CSL) grain boundaries with different crystallographic orientations along the [010] and [110] direction. In this process, the segregation energy is calculated for austenite grain boundaries. These structures were then transformed into martensitic configurations via a Bain transformation, allowing a direct comparison of segregation behaviour before and after the phase transformation.

Segregation energy calculations quantify whether a residual element thermodynamically prefers grain boundary sites or the bulk lattice. To calculate the segregation energy, there are four structures that are calculated, including bulk Fe, bulk Fe with the residual element, the Fe grain boundary, and the grain boundary with the residual element. A negative segregation energy refers to a preference for the residual elements sitting around the grain boundary, while a positive segregation energy indicates the material would more likely found in the bulk material. In this work, it is hypothesized that the preferential locations around the grain boundaries differ between austenite and martensite, so after quenching residual elements may not be at the most optimal positions and only diffuse to those positions during later heat treatments.

Along with calculating the segregation energy, the structures are further expanded upon to explore the cohesion energy of the grain boundary. This was done by comparing the energy of the residual elements at the grain boundary versus sitting at a free surface. Cohesion energy gives insight into the residual element influence on the grain boundary. If the residual element prefers to sit at the free surface, then it would be indicative the steel with the residual elements is more sensitive to intragranular grain fracturing. The reverse would be indicative of intergranular fracturing.

By combining the segregation energy and cohesion energy, comparisons of the grain boundaries before and after transformations can be made. This would provide insight into different grain boundaries propensity for fracturing based on the orientation of the grain boundary, the residual elements that are present, and post processing. Overall, WP7 delivered a physically grounded description of residual element behaviour at grain boundaries across phase transformations, providing both fundamental understanding and quantitative input relevant for predicting diffusion pathways, microstructural stability, and mechanical performance in martensitic steels.

7 WP8. Nano-engineering towards CO2 clean martensite

During the first reporting period, activities within WP8 focused exclusively on the Life Cycle Assessment (LCA) analysis, which is the only task scheduled for this phase. This work is essential to quantitatively evaluate the environmental performance of the steelmaking routes addressed in the project, particularly with respect to CO_2 emissions and resource efficiency, and to support the transition towards more circular, scrap-intensive steel production.

The main achievement of this reporting period was the completion of the goal and scope definition phase, conducted in accordance with ISO 14040 and ISO 14044 standards. A Gate-to-Gate approach was selected to focus the analysis on production stages under direct industrial control and optimisation potential, ensuring both relevance and comparability of the results.

A substantial part of the work addressed detailed process mapping for both BF-BOF and EAF routes, ensuring that the Life Cycle Inventory reflects the physical reality of the industrial plants rather than generic literature assumptions. Process flow diagrams were developed and validated accordingly. In parallel, the inventory compilation phase was initiated through the development of route-specific data collection templates covering material inputs, energy consumption, additives, and direct emissions.

In general, WP8 progressed as planned. The methodological framework and initial inventory work established during this reporting period provide a solid basis for completing the LCA and performing the impact assessment in the next reporting period.

8 WP9. Project dissemination

During the first reporting period, WP9 activities focused on establishing the communication, dissemination, and exploitation framework of the NANO-S-MART project and on initiating visibility building actions in line with the project timeline.

A comprehensive Exploitation, Communication and Dissemination Plan was prepared and submitted as Deliverable D9.1 by Month 6. This plan defines the overall strategy, key messages, target audiences, tools, and channels to be used throughout the project to maximise impact and ensure that project results are made accessible to the scientific community, industrial stakeholders, and relevant end-users. The plan is conceived as a living document and will be regularly updated as the project progresses and new results become available.

In the early phase of the project, communication and dissemination activities have focused primarily on raising awareness and building visibility, highlighting the project objectives, scope, and the multidisciplinary expertise of the consortium. In line with this strategy, the project website (https://www.nano-s-mart.eu/) has been established and regularly updated, serving as the main public interface for project information, news, and general dissemination content.

Additional dissemination actions have been carried out through social media channels, with particular emphasis on LinkedIn, to increase visibility among scientific, research, and industrial audiences. These channels are used to disseminate the most impactful news, mainly related to support for conferences and similar activities. They complement the project website and help expand the project's overall reach.

WP9 also aims to foster synergies with European initiatives relevant to sustainable steelmaking. In this context, initial engagement with the Clean Steel Partnership (CSP) and ESTEP has been achieved during the reporting period. Leveraging the active involvement of consortium partners in ESTEP, the project has established links with key stakeholders in the European steel research community. As a concrete dissemination action, the Project Coordinator participated in the ESTEP Spring Dissemination Event in Brussels (https://www.nano-s-mart.eu/the-coordinator-dr-pello-uranga-attended-the-estep-european-steel-technology-platform-spring-dissemination-event-2026/), contributing to external visibility of NANO-S-MART and supporting alignment with broader Clean Steel objectives.

9 References

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