Executive Summaries of Confidential Deliverables (SEN) submitted during M1-M24

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Revision	*Date*	*Description*
1	28/02/2025	SEN Deliverables submitted during first half of the project
2	14/04/2025	Addition of executive summaries for D5.1 and D7.1
3	17/07/2025	Addition of executive summaries for D5.2 and D10.2

Report contributors		
Name	Beneficiary Short Name	Details of contribution

Table of Contents

1. Executive Summary

This report is a compilation of all the executive summaries of the confidential deliverables (SEN) that have been submitted during the first half (M1-M24) of the FP4-Rail4EARTH project.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description

3. Executive Summary D2.1 - Adaptation to climate change intermediate report n°1

The objective of FP4-Rail4EARTH/WP2 is to identify the solutions to increase the resilience of the European railway system to the current and future climate conditions.

The method is to implement the EU adaptation strategy to the railway sector, structured at this stage around its two first objectives ‘Smarter adaptation’ and ‘Faster adaptation’.

The chosen approach is to collect, share and benchmark existing knowledge on assessment tools and adaptation solutions. This knowledge is acquired through literature reviews, detailed presentations of return of experience, and internal initiatives by the companies in the consortium.

Analysis of the knowledge base has highlighted the need to carry out vulnerability studies for all railway assets.

For rolling stock, adaptation to heat waves is a priority, with technical solutions such as high-performance cooling systems to maintain thermal comfort and equipment availability.

For stations and infrastructure, it is essential to deploy advanced technologies for their monitoring and management, including early detection systems and modelling tools to anticipate the impacts of climate change and plan interventions accordingly.

For infrastructure, the use of more resistant materials, the design of structures capable of withstanding higher temperatures or more intense rainfall, and the installation of water management systems are all necessary.

This study has identified the pre-existing methodological tools that enable evidence-based decision-making and strengthen the resilience of railway assets and operations to climate change. It serves as a solid basis to guide future research decisions and develop the tools and methodologies needed to prioritise adaptation actions, taking into account trade-offs and involving relevant stakeholders in the decision-making process.

Finally, through the various tasks and sub-tasks of this project, which will benefit from the results of this study, it is proposed to continue research in this area, focusing on the development of climate change prediction and risk assessment tools specific to the rail sector, in order to further improve the resilience of the European rail system.

4. Executive Summary D3.1 - Noise and Vibrations intermediate report n°1

This document constitutes the deliverable D3.1, Noise and Vibrations intermediate report no. 1, under the framework of the Flagship Project FP4 – Rail4EARTH as described in the EU-RAIL MAWP.

This document has been drafted to report on the status of the work package after 16 months, including on the status of the various tasks within this work package:

- 3.1 Further improvement of noise source characterisation
- 3.2 Noise perception indicator
- 3.3 Noise and vibration emissions over lifespan
- 3.4 Development of effective mitigation measures of ground-borne vibration
- 3.5 Squealing noise

Progress is running according to plan; there are no major deviations to be reported.

5. Executive Summary D4.2 - Circular Economy Solutions intermediate report n°1

The objective of FP4-Rail4EARTH/WP4 is to develop sector methodology and tools for the efficient implementation of circular economy solution in the railway sector. The work of the work package has been divided in two tasks, with the first task focusing on environmental data management tool and environmental indicators, and the second task on circular economy solutions. Altogether, this work package will propose solutions aiming at fighting climate change, optimizing railway environmental impacts and ensure railway business continuity through developing circular economy solutions.

The chosen approach involves identifying and researching existing knowledge on environmental data tools, environmental indicators, and circular economy solutions. This knowledge has been gained through literature reviews, workshops with the consortium partners, questionnaires, interviews, research and development supporting circular economy flow in the railway sector. This approach provides a solid foundation for guiding further decisions.

Thus far within task 4.1, a benchmark has been done of the indicators, methodology, tools for managing environmental data, and labels, along with their metrics, currently employed in the railway sector. Furthermore, the consortium has developed a consolidated list of criteria and requirements that establishes a shared vision of what characterises an ideal label, which has resulted in the creation of an assessment matrix that can effectively characterize the level of performance of an ecolabel in terms of the consortium's consolidated expectations.

Task 4.2 has developed methodologies aimed at identifying circular levers that offer environmental and economic benefits to the railway sector. Inflows and outflows of materials are analysed along linear pathways to pinpoint materials where circularity can be enhanced. Additionally, lifespan extension and reuse mechanisms are being studied by sizing the second-hand railway market in Europe, standardizing requirements for second-hand parts management and developing specifications for dedicated marketplaces. Specific solutions have also started to be investigated aiming at reducing the environmental footprint of some railway systems and materials, for the catenary and station systems and for the development of recycled carbon fibre products in particular.

As of now, the overall conclusion is that the groundwork for further work and research has been established, and the progress of FP4-Rail4EARTH/WP4 is according to the plan.

6. Executive Summary D5.1 - Development of alternative propulsion based on ESS intermediate report n°1

The present document constitutes the Deliverable D5.1 “Development of alternative propulsion based on ESS intermediate report n°1” in the framework of the Flagship Project FP4 – Rail4EARTH as described in the EU-RAIL MAWP.

The activities carried out up to now within the FP4 WP5 led to the drafting of this first version of the document which reports the status of the SP1-WP5 of Rail4EARTH after 12 months of work on the different tasks:

- Requirements and study of alternative propulsion systems based on next generation ESS: Task to be completed in 2023. Final conclusions are presented in this document. In the frame of the works performed in Task 5.1 there has been a collaboration with FP6 on light trains requirements for regional lines. The collaboration has been successfully closed with the generation of a comparative table of requirements for the long range BEMUs and the light trains. The main conclusion is that requirements are not compatible due to the differences in the trains being used on both projects.
- Development of innovative next generation propulsion system components: Task to be completed in 2024, progressing according to the plan. In the frame of the works performed in Task 5.2 there has been a collaboration with Batt4EU on battery technologies to be continued in 2024.
- Energy management models and optimization: Task to be completed in 2024, progressing according to the plan.
- Methods and tools for virtual validation/certification: Task to be completed in 2024, progressing according to the plan.
- Power Semiconductors Reliability: Task to be completed in 2024, progressing according to the plan.

As this Report is the first intermediate WP5 progress report, some chapters are not fully completed because the work will be completed on 2024 calendar year. The progress is according to the plan, no major deviations to be reported.

7. Executive Summary D5.2 - Development of alternative propulsion based on ESS Final report

The present document constitutes the Deliverable D5.2 “Development of alternative propulsion based on ESS” in the framework of the Flagship Project FP4 – Rail4EARTH as described in the EU-RAIL MAWP.

The activities carried out within the FP4 WP5 led to the drafting of this final version of the document which reports the status of the SP1-WP5 of Rail4EARTH at completion of work on the different tasks:

- Requirements and study of alternative propulsion systems based on next generation ESS: Task to completed in 2023. Final conclusions are presented in this document. In the frame of the works performed in Task 5.1 there has been a collaboration with FP6 on light trains requirements for regional lines. The collaboration has been successfully closed with the generation of a comparative table of requirements for the long range BEMUs and the light trains. The main conclusion is that requirements are not compatible due to the differences in the trains being used on both projects. Even if the work in this task was closed some modifications and conclusions have been included in this task from the intermediate report based on the experience gained from T5.2 developments and the link with WP1 – Standardization.
- Development of innovative next generation propulsion system components: In this WP new traction system components to improve efficiency and, hence, autonomy of the BEMU have been developed. Some of the subsystems some are based on SiC semiconductor technology, other use advance IGBT technology with design targeting the energy consumption reduction. Innovative ESS components, including battery packs and thermal management systems, were designed, meeting targets for energy density, cost efficiency, operational robustness, and safety. Prototype components were successfully assembled and first tests in laboratory performed confirming improved energy efficiency and operational range objectives for long-range BEMUs. Main part of the validation in lab will be carried out during the second part of the project in WP6. In Task 5.2 there has been a collaboration with Batt4EU on battery technologies to be continued in WP6 if new inputs are available.
- Energy management models and optimization: Linked to work done in the components development task, partners working in this task conclude that it seems feasible to increase the range in autonomy up to the 200km target. To get to this conclusion and make the autonomy target feasible the working group defined a set of technical items able to decrease energy consumption, compared simulation tools and define a standard methodology to calculate energy savings by several partners based on a generic train used as a reference for KPI evaluation.
- Methods and tools for virtual validation/certification: Several simulation methodologies have been developed and used from degradation modelling of components such as

semiconductor and battery cells. The complete system architecture is defined and modelled into HIL (Real-time simulator) and MIL (Simulink/matlab) environment. For train simulation, a complete system modelling including infrastructure installation configuration was detailed in order to guarantee the battery performance over a line e.g. the SoC level at the end of the mission profile.

- Power Semiconductors Reliability: Steps towards higher reliability of power semiconductors in railway applications have been taken by refining the environmental requirements especially considering icing and condensation. Working closely together with power semiconductor suppliers within the ECPE PSRRA Working Group a test specification for condensation testing has been developed. A mathematical model to not only predict the lifetime of components in the field but also the impact of degradation on their properties was analysed and assessed. Also, a thorough analysis of SiC-MOSFET specific reliability topics relevant for railway application was performed by literature research and engaging with experts. Addressing the topic of capacitor safety, a risk evaluation based on EN 50126 was prepared which highlights the importance of the topic."

This report compiles the main contributions to the first intermediate WP5 progress report and those generated during the second year of the project (plus 6 months of extension). WP5 is directly linked to WP6 where the test of the components is to be performed at system level in power laboratory and HIL.

8. Executive Summary D7.1 - Development of alternative propulsion based on hydrogen intermediate report n°1

The present document constitutes the Deliverable D7.1 "Development of alternative propulsion based on hydrogen intermediate report n°1" in the framework of the Flagship Project FP4 – Rail4EARTH as described in the Grant Agreement.

This document has been prepared to provide the status of WP7 of Rail4EARTH after 12 months of working, and it is reported the status on:

- H_2 Storage system both CFRP and Steel.
- H_2 hybrid Locomotive.
- System to improve the efficiency of the H_2 power plant embarked on the train (Fuel Cell + auxiliaries' equipment) and the energy management system. The energy management system is the control system to deliver the requested electrical power to the traction system via the control of H_2 and O_2.
- Standardization of refuelling interfaces.

The following table shows the progress of works related to each task defined in the Grant agreement:

Task and progress	Principal activities	Status
7.1 Developments on H2 storage technologies for on-board railway application. 50%	Selection of the metallic material and the effect of high-pressure hydrogen in the long-term mechanical reliability of the vessel in harsh conditions of vibration and impact.	H2 Storage system both CFRP and Steel.
	Innovative simulation methods and monitoring systems for cost-effective and safe hydrogen storage in rail vehicles, to provide more reliable simulation methods for the design of lightweight hydrogen tanks for rolling stock and, this way, to reduce the use of materials.	Progressing on modelling, lab-scale testing, and characterisation.
	A new innovative hybrid design (type IV) with minimal liner thickness. This will maximise load carrying capacity with minimum weight of the tank.	
	Integration of a Structural Health Monitoring System (SHM) including damage assessment.	Health Monitoring System tested on standardised test.
	Mechanical design and mechanical reliability assessment of the designed tank.	Exploring the instrumentation of commercial tank on the demonstrator.
7.2 Developments on energy management and	Analysis, evaluation, and assessment of wasted energy flows and their dynamics in hydrogen train applications based on real	H2 hybrid Locomotive: Installation completed, first movement inside the factory,

Task and progress	Principal activities	Status
increase of efficiency of the global system (uses of wasted energy). 50%	life use cases: wasted heat and potential energy of pressure tanks (pressure drop).	pending for testing on track.
	Identification of technologies and systems to exploit the wasted energy.	System to improve the efficiency of the H2 power plant and the energy management system: - Once the considered systems have been defined, a dataset has been identified for measuring during on-track test for decision making. - The efficiency of the current H2 power plant will be measured for detailed design of recovery wated energy. - One or two solutions will be selected for detailed development and implementation in the following WP8.
	Benchmark of technologies and systems.	
	Development of the power electronics needed to integrate hybrid systems.	
	Evaluation of the improvement at train level in terms of efficiency, range, etc.	
7.3 Requirements for hydrogen refuelling. Link with standardization activities and refuelling stations. 30%	Update the state-of-the-art of alternative drives, based on preliminary works done in S2R PINTA3 WP3, to synthetise the progress in the performance of alternative propulsion systems based on hydrogen.	Following with the land vehicle standardisation until the detection of specific needed from the partners. Further communication programmed with WP9 and WP1 to fix position.
	Comparison with conclusions from S2R PINTA3 WP3 report to know the evolution of alternative drive performances.	
	Study of the requirements and required inputs for the production, storage and refuelling of hydrogen for railway vehicles.	
	Definition of a model of Hydrogen Station in Railway (HRS) interoperable, intermodal (trucks, cars...) standardise for rail supply.	
	Definition of common interfaces (mechanical, communication, etc.) from the rolling stock together with the establishment of procedures for refuelling H2.	

Table 1. Progress of works

9. Executive Summary D7.2 - Requirements and specification for Hydrogen storage and energy management strategies final report

The present document constitutes the Deliverable D7.2 “Requirements and specification for Hydrogen storage and energy management strategies final report” in the framework of the Flagship Project FP4 – Rail4EARTH as described in the Grant Agreement.

This document has been prepared to provide the status of WP7 of Rail4EARTH after 24 months of working, and it is reported the status on:

- H_2 Storage system both CFRP and Steel.
- H_2 hybrid Locomotive and other demos (HEMU and Yellow Fleet).
- System to improve the efficiency of the H_2 power plant embarked on the train (Fuel Cell + auxiliaries’ equipment) and the energy management system. The energy management system is the control system to deliver the requested electrical power to the traction system via the control of H_2 and O_2.
- Standardization of refuelling interfaces.

The following table shows the progress of works related to each task defined in the Grant agreement:

Task and progress	Principal activities	Status
7.1 Developments on H2 storage technologies for on-board railway application. 50%	Selection of the metallic material and the effect of high-pressure hydrogen in the long-term mechanical reliability of the vessel in harsh conditions of vibration and impact.	H2 Storage system both CFRP and Steel.
	Innovative simulation methods and monitoring systems for cost-effective and safe hydrogen storage in rail vehicles, to provide more reliable simulation methods for the design of lightweight hydrogen tanks for rolling stock and, this way, to reduce the use of materials.	Progressing on modelling, lab-scale testing, and characterisation. Integration of a Structural Health Monitoring System (SHM) including damage assessment.
	A new innovative hybrid design (type IV) with minimal liner thickness. This will maximise load carrying capacity with minimum weight of the tank.	Thanks to modelling and testing steps done to optimize type IV tanks done.
	Integration of a Structural Health Monitoring System (SHM) including damage assessment.	Health Monitoring System tested on standardised test.
	Mechanical design and mechanical reliability assessment of the designed tank.	Exploring the instrumentation of commercial tank on the demonstrator.
7.2 Developments on energy management and	Analysis, evaluation, and assessment of wasted energy flows and their dynamics in hydrogen train applications based on real	H2 hybrid Locomotive: Installation completed, first movement inside the factory,

Task and progress	Principal activities	Status
increase of efficiency of the global system (uses of wasted energy). 50%	life use cases: wasted heat and potential energy of pressure tanks (pressure drop).	pending for testing on track. Measurements done.
	Identification of technologies and systems to exploit the wasted energy.	System to improve the efficiency of the H2 power plant and the energy management system: - Once the considered systems have been defined, a dataset has been identified for measuring during on-track test for decision making. - The efficiency of the current H2 power plant will be measured for detailed design of recovery wated energy. - One or two solutions will be selected for detailed development and implementation in the following WP8. Values obtained for the technologies selected.
	Benchmark of technologies and systems.	
	Development of the power electronics needed to integrate hybrid systems.	
	Evaluation of the improvement at train level in terms of efficiency, range, etc.	Values of improvements obtained for each technology.
7.3 Requirements for hydrogen refuelling. Link with standardization activities and refuelling stations. 30%	Update the state-of-the-art of alternative drives, based on preliminary works done in S2R PINTA3 WP3, to synthetise the progress in the performance of alternative propulsion systems based on hydrogen.	Following with the land vehicle standardisation until the detection of specific needed from the partners. Comparison with conclusions from S2R PINTA3 WP3 report to know the evolution of alternative drive performances. Great advance on common working meeting.
	Comparison with conclusions from S2R PINTA3 WP3 report to know the evolution of alternative drive performances.	
	Study of the requirements and required inputs for the production, storage and refuelling of hydrogen for railway vehicles.	
	Definition of a model of Hydrogen Station in Railway (HRS) interoperable, intermodal (trucks, cars...) standardise for rail supply.	
	Definition of common interfaces (mechanical, communication, etc.) from the rolling stock together with the establishment of procedures for refuelling H2.	

Table 2. Progress of works

10. Executive Summary D9.1 - Interoperable Hydrogen Refueling Station intermediate report n°1

This report D.9.1 Interoperable Hydrogen Refueling Station intermediate report n°1 shows progress in Work package 9 Interoperable Hydrogen Refueling Station Flagship Project 4 Rail4Earth.

The aim of this WP is to develop concept of Interoperable Hydrogen Refueling Station. That means Hydrogen Refueling Station that can provide hydrogen for different types of rolling stock. That means that this type of refuelling station is focussed to work with more than one railway operator that need hydrogen source for its vehicle.

The approach of that development focusses on 4 areas:

First is localisation of Hydrogen Refueling Station. Today companies that have hydrogen vehicles like rolling stock or buses build their own HRS near or inside depot. In WP9 approach is focused on open access refuelling station.

Second area is focusing on Safety Framework for designing hydrogen refueling station.

Third area in modelling of hydrogen refuelling process that will be use to examine different system combination with use on different types of rail vehicles. It also can be used for multimodal approach like refuelling road vehicles such us trucks, buses etc.

Fourth area is designing new interface of ruling station that can exceed higher flow of hydrogen, and have communication interface.

This deliverable shows that even many aspect of refuelling station for railways can be taken from road vehicle industry there are crucial differences that must be consider.

11. Executive Summary D10.1 - Smart infrastructure power supply intermediate report n°1

The present document constitutes the deliverable document D10.1 “Smart infrastructure power supply intermediate report n°1” in the framework of the Flagship Project 4 - Rail4EARTH project under Grant Agreement n°101101917 of the Europe's Rail Joint Undertaking.

It is one of the deliverables of the work package 10 (referred to as WP10): “Smart Infrastructure Power Supply”. The main objective of WP10 is to develop and integrate innovative solutions to improve and enhance the infrastructure power supply.

The intermediate report describes the advancement made in each task defined in the Grant Agreement (GA) for WP10.

In the first part, the deliverable provides an overview of the work conducted in task 10.1 aiming to study the implementation of FACTS (Flexible Alternating Current Transmission Systems) to enable double side feeding in 25 kV 50 Hz AC railway system which differs from conventional 25 kV 50 Hz rail power supply that is based on island supply topology. This part includes the elaboration of the generic requirements for Static Frequency Converter (SFC) and Railway Interline Power Flow Converter (RIPFC) systems as well as investigations on topologies and control strategies of those converters. Use cases are also described in this chapter that will serve for load-flow studies and help for the identification of a demonstrator site. As this document is due to M16 of the project, the chapter will not conclude a choice of a control strategy for RIPFC or SFC. The co-simulation between SNCF and SMO and load-flow simulations of the use cases will be the next focus on this task and will allow to have a better insight on the strategies.

In the second part, the document depicts the advancement of task 10.2. The objective of this task is to study the integration of an energy storage system into AC railway network. A quick introduction on DC and AC railway systems is followed by the description of the Swedish railway system that will be the basis for simulation. To mitigate some power quality issues that can occur in the Swedish railway system (voltage sag, currents harmonic-resonance, instabilities…), energy storage system (ESS) solutions are proposed and studied through simulation. Two cases have been studied to illustrate the effect of voltage sag mitigation and to confirm the function of regenerative braking energy recovery for one topology of ESS. Other cases and topologies will be modelled as the work progresses on this task.

The third part presents the advancement of task 10.3. The task consists in finding methodologies and developing a software tool enabling to optimize the railway grid during the design phase and operational planning stage. Two use cases, one in 1500 V DC in the Netherlands and one in 2x25 kV Ac in Spain, have been investigated to build an AC and a DC model to perform power flow simulations. The models will then form the basis for smart optimization algorithms aimed at decreasing energy consumption across the entire operational system.

In terms of KPIs, WP10 is linked either directly or indirectly to 3 main KPIs of FP4 project:

- Physical energy consumption (train, infrastructure, station)
- Physical CO2 equivalent emissions

- Life Cycle Costs reduction

For each task of this WP, the period from M1 to M16 have been mainly dedicated to establishing models and use cases. In the next steps of the project, use cases will be simulated or further analysed to give insight on energy savings and C02 equivalent emissions. The study of different infrastructures scenarios on use cases will allow to evaluate LCC reductions.

12. Executive Summary D10.2 - Design and control strategies for energy storage integration in AC infrastructure

The document depicts the advancement of task 10.2. This work develops a comprehensive system-level simulation model of the Swedish railway traction power system based on real-world field data. The model includes detailed sub-models of static frequency converters (both DC-link and multilevel topologies), electrical locomotives, catenary systems, high-voltage feeder lines, and traction transformers. Its validity is demonstrated through two representative case studies. Various energy storage solutions and corresponding interface converter technologies are investigated and evaluated for the energy storage system (ESS) deployment in railway applications, with a final focus on Li-ion batteries, supercapacitors, flywheel ESS and superconducting magnet energy system (SMES). A dedicated DC-AC converter topology is designed to support ESS integration, aiming to enhance voltage stability and facilitate regenerative braking energy recovery. The performance of the proposed converter, in combination with the four selected ESS technologies, is evaluated with and without a bidirectional DC-DC converter. Furthermore, a novel ESS integration method into existing static frequency converters is proposed to enable peak power shaving and improve the utilization of regenerative energy. This approach is demonstrated using a multilevel converter equipped with supercapacitors, with performance assessment conducted through the developed simulation framework.

13. Executive Summary D11.2 - Requirements and validation plans for energy hubs solutions, preliminary developments and guidelines for energy hubs final report

This document presents the findings and conclusions of our work package on advancing energy hubs within rail infrastructure. The work package includes two main outputs, each aligned with the project's primary work streams. This specific deliverable focuses on energy hubs, establishing a foundation for future developments in Work Package 12, with a key objective of enhancing energy flexibility and resilience in Electrical Smart Grids through energy hub deployment.

Work in Work Package 12 will build upon this foundation, translating shared insights into practical pilot projects supported by partners across different regions. Following a structured approach of requirement definition, validation planning, and preliminary development, we have prepared several pilot cases for the next implementation and demonstration phase. Each pilot addresses unique objectives: an urban light rail project in the Netherlands tests light rail-specific concepts; a project in Poland addresses particular railway grid conditions through Li-ion energy management; a Dutch pilot in the 1.5 kV DC traction system demonstrates a scalable model for flexible power control; an Italian DC-side storage project integrates renewable energy with braking energy capture; and a Polish AC-side project maximizes renewable use and regenerative braking.

These pilots foster a shared understanding among stakeholders, enabling collaborative progress and synergy discovery across various contexts. Given the relative novelty of energy hubs, standardizing KPIs has been challenging; however, three core KPIs—physical energy consumption, physical CO_2 equivalent emissions (Life Cycle Assessment), and life cycle cost reduction—have been established. These metrics, supported by local KPIs such as energy cost savings and reduced investment costs, will allow detailed performance assessment. Additional considerations such as peak shaving, space utilization, and comparisons with conventional technologies further contribute to a comprehensive evaluation of economic and operational impacts.

The pilots highlight the importance of integrating diverse energy carriers to improve flexibility and enable coordination between rail and national grids. Emphasizing storage systems for effective peak management and grid support, while addressing governance and regulatory variations, could necessitate updates to harmonize collaboration among grid operators. Collectively, these efforts enhance grid flexibility, adapt to renewable energy demands, and improve stakeholder coordination across varied national contexts.

14. Executive Summary D11.3 - Requirements and validation plans for green buildings solutions, preliminary developments for green building solutions final report

The main objective of WP11 is to enhance energy management at the station level (stations as energy hubs) and to increase the flexibility and resilience of Electrical Smart Grids. WP11 is responsible for defining the requirements and preliminary developments necessary for implementation and demonstration in WP12 for energy hubs and in WP13 for stations. This work comprises the definition of functional and technical requirements for the pilots and the design of a validation plan to be completed at the end of the demonstration phase.

Deliverable 11.1 presented the initial progress on Railway Energy Hubs and Smart Green Railway Stations. It outlined the different use cases, requirements, recommendations, validation plan and next steps. Deliverable 11.3 builds on the work presented in Deliverable 11.1, focusing specifically on Smart Green Railway Stations.

In the context of Building a Modular Low-Emission Station, this deliverable builds upon the modular construction approach introduced in D11.1. The document focuses on the development of specific requirements for the architectural and construction issues of stations, as well as the definition of Common Data Environment (CDE) recommendations are designed to enhance digital workflows. In terms of preliminary developments, work has been conducted on the collection and analysis of data from physical buildings, as well as the creation of virtual building models that adhere to Building Information Modelling (BIM) standards. A comprehensive explanation of the testing scenarios has been conducted with the objective of validating data integration and interoperability within collaborative environments for the CDE. Moreover, demonstration plans for both modular stations and CDE have been developed, thereby providing a solid foundation for practical implementation in real-world scenarios.

In this Deliverable, the Railway Station Energy Digital Twin project advances beyond the initial conceptualisation outlined in D11.1. This is achieved by progressing the development of sensor requirements, creating the station Building Information Model (BIM) and developing energy modelling. These efforts are tailored to ensure that the digital twin can provide actionable insights for energy efficiency and asset management during pilot implementations. Additionally, this deliverable develops the validation and demonstrator plans, which detail the evaluation methodology and processes involved.

In conclusion, the guidelines for stations and the conclusions drawn from the work conducted in this deliverable are presented.

This deliverable thus constitutes the foundation for WP13, in which the proposed technologies will be validated through two real-world pilots: a new modular station in Poland and an existing station in Spain utilising a digital twin approach. The objective of both pilots is to demonstrate the potential for sustainable, efficient, and user-centric railway infrastructure.

15. Executive Summary D14.2 - Development of air-less bogie, including electro-mechanical brake and air-less suspension final report

This report provides the final results & status of the completed tasks as described into the Project Grant Agreement related to Work Package n°14 - Development & integration of electro-mechanical systems supporting air-less train and more specifically to the development of air-less bogie, including electro-mechanical brake and air-less suspension.

The report is therefore divided into two main sections; one related to the research & development of Electro-Mechanical Brakes (EMB) technology and the other related to the concept definition of an air-less suspension solution.

First task involves a technical review of current railway standards (EN, TSI,…) to evaluate the impact of an airless approach with current legislation & rules.

This normative analysis has shown significant impact to the current list of applicable standards especially regarding the brake system scope to move from traditional pneumatic-operated systems to airless / Electro-Mechanical Brake systems. About suspensions, the analysis carried out to date does not show particular obstacle as the intention from the task working group is to analyse a concept which can still be compatible in complying with the existing rules & standards as they are written today. Output of these normative studies shall then be used as inputs to the relevant standards revision working groups.

Regarding the technical part related to EMB products development, it demonstrates the EMB system technologies of both Knorr-Bremse and Wabtec Faiveley have reached their commitment in terms of TRL scale progress for the end of WP14, respectively TRL7 and TRL5. Moreover, the report also delivers the technical progress regarding on-train demo preparations which will take place over the course of WP15 activities.

The technology identification related to suspensions will eventually lead to have an experimental proof of concept led by Alstom and TRV. At this stage of the program, the report shows a concept formulated of air-less suspensions, thus demonstrating a TRL2 maturity on this scope.

16. Executive Summary D14.3 - Development of air-supply independent pantograph final report

This report provides the final results & status of the completed tasks as described into the Project Grant Agreement related to Work Package n°14 - *Development & integration of electro-mechanical systems supporting air-less train* and more specifically to the development of air-less pantograph technology.

The report is divided into two main sections; one related to the research & development of an electro-mechanical pantograph airless or air-supply independent technologies and the other involving a technical review of current railway standards (EN, TSI,…) to evaluate the impact of an airless approach with current legislation & rules.

This normative analysis has shown impacts to the current list of applicable standards which will most likely require standards revision working groups to take as inputs the comments and proposals from this WP14 working group in order to prevent introduction or qualification obstacles of the new technology.

Regarding the technical part related to pantograph products development, the report demonstrates the technologies of both companies Wabtec Faiveley and Siemens Mobility have reached their commitment in terms of TRL scale progress for the end of WP14, respectively TRL5 and TRL4. Moreover, the report also delivers the technical progress regarding on-train demo (WT) and adapted test bench (SMO) preparations which will take place over the course of WP15 activities.

Additionally, TRV has built an initial simulation to investigate the requirements for the simulation environment of the dynamic interaction between electro-mechanical pantograph and catenary. The report provides the details about the model used, the initial simulation findings as well as the next simulation steps in order to optimise the control strategies expected during WP15.

17. Executive Summary D16.2 - High performances running gear architectures and materials final report

The present document constitutes the Deliverable D16.2 “High performances running gear architectures and materials final report” in the framework of the Flagship Project FP4 – Rail4EARTH as described in the EU-RAIL MAWP.

This document has been prepared to provide the status of the SP4-Running Gear of Rail4EARTH after 24 months of working, and it is reported the status on:

- Lightweight solutions for running gear.
- New running gear architectures

The progress is according to the plan, no major deviations to be reported.

18. Executive Summary D16.3 - High-performance drive final report

The present document constitutes the Deliverable D16.3 “High-performance drive final report” in the framework of the Flagship Project FP4 – Rail4EARTH as described in the EU-RAIL MAWP.

This document has been prepared to provide the status of the SP4-Running Gear of Rail4EARTH after 24 months of working, and it is reported the status on:

- High efficiency drives
- Active steering

The progress is according to the plan, no major deviations to be reported.

19. Executive Summary D18.2 - Assessment of railways adaptation of eco-friendly HVAC final report

The climatic challenge, on one side which we are facing on, supported by the evolution of different regulations (Phase out of HFCs till 2030, PFAS regulation planned for 2026) and on the other side, geopolitical events (war in Ukraine) which cause massive energy costs fluctuation push all the railway parties (railway operators, train builder and the components suppliers) to challenge the state of the art of HVAC's technologies for rolling stock. The need to develop eco-friendly HVAC to comply with the new regulation and to bring a sustainable environmental effort by increasing the efficiency of the HVAC units become more than essential.

The state of the art of HVAC technology for rolling stock is HVAC units based on Vapour Compressor Condenser (VCC) system using HFC (usually R134a in Europe). This baseline needs to move and to be pushed forward to fulfil the challenge cited above.

Knowing it, an assessment matrix with different KPIs and weighting has been developed with the stakeholders of this working group. This matrix allows to compare, as objectively as possible, based on selected baseline (climatic zone, type of train, number of passengers, …) the different technologies existing and available on the market. The KPIs taken in consideration cover a large range of aspects from the Life Cycle Costs, energy consumption and the carbon footprint, but also the intrinsic aspects of HVAC units installed on trains like potential effort required to adapt train, weight, space envelope impact or the respect of the operation at the limits (by low and high ambient temperatures) of the assessed technology.

Then a survey of the "cooling" technologies has been made with a preselection of the technology, based on KPI's exclusions parameters agreed in the evaluation matrix, to be deepen analysed.

From this technology survey, it comes out that no other technology can supplant the well-known VCC technology at the time. Nevertheless, new refrigerant categories must be considered, like R290 refrigerant and energy enhancing technologies for VCC, like heat pump need to be further developed for near future application.

Those improvements and the support of the regulation authorities by standardizing the safe handling and operation of R290 HVAC system in railway application, would help to move the limits known up per today, and help to meet our target to develop eco-friendlier HVACs units.

20. Executive Summary D21.2 - Air flow analysis final report

The aim of the present deliverable “D21.2 – Air flow analysis final report”, is to summarize the experimental and numerical investigations of the tasks 21.1 within this work package “Rolling stock on board air quality developments” to give an overview over the performance of the current state-of-the-art ventilation concepts with respect to aerosol dispersion and the underlying mechanism. Based on that, it also includes the development and investigation of novel ventilation concepts reducing the spread of aerosol containing potential pathogens or pollutants.

For that, both a set of task-specific KPI and a selection of relevant state-of-the-art concepts were determined.

The result of our experimental and numerical investigations show that the selected state-of-the-art concepts show only a small amount of variation with respect to the KPI. Also, concepts performing better for one KPI often have drawback regarding other KPI.

This shows that the performance of state-of-the-art concepts is determined by the limitations of their common class, mixing ventilation. This means adjustment through the choice of a state-of-the-art ventilation concept are strongly limited to trade-offs between intensity and range of the aerosol exposure or how sensitive certain concepts are on the specific source location.

To address this, the novel concepts incorporate a more direct supply of fresh air to the breathing zones and source-near suction. These functions can be implemented in the form of active headrests or hat racks.

For the headrests, the investigations showed, that – while both functions are already advantageous on their own – the best results could be achieved by a combination of both, leading to reduction of the aerosol concentration of 60 % for the seats right next to the source and almost 50 % overall. These results were achieved while maintaining reasonable draught rates, supporting the applicability of further optimized versions of such concepts, which would significantly increase the resilience against disease spread inside train passenger compartments.

The hat rack units also show promising results by accelerating the aerosol decay up to 3 times against the reference case.

21. Executive Summary D21.3 - Feasibility study of air purification technologies final report

The aim of the present deliverable “D21.3 – Feasibility study of air purification technologies” is to present the investigations, analyses and results with regards to air improvement technologies, carried-out in the framework of Task 21.2 “Evaluation of air quality improvement technologies” within work package WP21 “Rolling stock on board air quality developments”.

For Task 21.2 the main goal was to analyse and group the technologies of air purification available on the market and evaluate which technologies are the most promising for the application in Rolling Stock. To assess the potential technologies as objective as possible a common evaluation matrix had to be created. At first to fully grasp the necessary framework conditions a survey of the current normative guidelines and standards was done. In the next step among others, the baseline configurations and the local key performance indicators, i.e., the most important evaluation parameter, for the different tasks were discussed in the task meetings with all partners and the results of these discussions were summarized in this deliverable. Here, the working document on the KPIs and their weighting is presented in this deliverable. As next step the different air purification technologies available on the market were scanned, analysed and grouped. Finally, the developed evaluation matrix was used to assess the considered technologies regarding their air quality improvement. Then the suitability of the technologies for application in rail vehicles was reviewed and discussed. The results of the evaluation are presented in this deliverable.

Except for the excluded ozone generator technology, all other considered technologies have advantages and some inconveniences for the different chosen criteria, which are compensating each other in the ranking and lead to a comparable evaluation at the end. This resulted in an overall score in a relatively small range, where no technology really sticks out. The chosen focus of a planned application in RS can therefore be decisive for the selection of a technology. In this tight filed the Needlepoint Bipolar Ionization and Dielectric Barrier Discharge both achieved the highest overall score. According to the weighted KPIs, those two technologies have the best trade-off between efficiency, costs and applicability (space requirements, added weight, retrofit). The findings of this Task 21.2 can be used as inputs for WP22, where the most feasible technologies for Rolling Stock will be validated through different test campaigns.

22. Executive Summary D21.4 - Test procedure for air quality evaluation final report

The aim of the deliverable “D21.4 – Test procedure for air quality evaluation” is to present the methodology and the different protocols of testing proposed by the task 21.3 within this work package WP21 “Rolling stock on board air quality developments” to evaluate solutions to protect passenger and technical staff .

At first, to do this, we introduce the issue of air pollution in general and its impact on air quality by providing some background information on this subject relative to the different types of pollutants, the future development of air quality in Europe and by showing that the main concern in the rail sector would be urban transport, especially the metro, and this one is the priority.

Secondly, for the protocol development, we introduce a specific process with a part including a methodology for design and validation of protocols, a protocol maturity scale to indicate the maturity of them, a testing strategy with a systematic approach based on the target, the medium and scale of testing. For this one we define 3 levels of maturity for the validation of the solutions: component level, mock-up level and train level.

Then, we describe the different families of pollutants, pathogens and surrogates to take into account in our study and their prioritisation levels and after we propose a protocols catalogue at component and mock-up levels in order to address at least the TRL4 maturity for the validation of solutions through the 3 domains of activities (Air Treatment, Surface Treatment and Air Quality Micro-Sensors).

The main protocols are presented and validated in laboratory and mock-up conditions, with a good level of results for the repeatability and they must be followed afterwards to confirm their robustness.

In addition, we present a benchmark and evaluation of various families of micro-sensors (low-costs) for air quality assessment, today only the particulate matter micro-sensors could be enough mature. It will also focus on presenting this information by a visualization tool which could include an Air Quality Index specially defined for railways application and synthesizing the air quality for a control center of the Railway Undertaking.

Moreover, to illustrate the works, we give some results with a good efficiency of solutions tested: measurement of particulate matter by micro-sensor, various families of filters, and different surface treatment solutions based on coating and lighting.

In conclusion, the Task 21.3 proposed relevant and repeatable protocols for the validation of air (and surface) purification solutions, benchmarked and evaluated different families of micro-sensors to qualify the air quality indoor train, summarized possible visualization tools as well as discussed different existing Air Quality Index.

23. Executive Summary D23.1 - Air Quality on covered platforms and tunnels intermediate report n°1

The present document constitutes the Deliverable D23.1 “Air Quality on covered platforms and tunnels intermediate report n°1” in the framework of the Flagship Project 4 – Rail4Earth, Work Package 23 Air Quality on covered platforms and tunnels, as described in the EU-RAIL MAWP.

This document has been prepared to provide the status and progress of the WP23 until M16 (March 2024). It focuses on work realized in the three first tasks of this WP23.

Concerning the development of a pre-standardised method to measure, compare and report the air quality on covered platforms and in tunnels (§ 6), a literature review was first carried-out. It describes the different types of pollutants and focuses on the measurement of Particulate Matter such PM10 and PM2.5. It outlines the various methods and equipment used for measuring air quality within railway environments.
In addition, a review of the different recommendation guides published concerning air pollution in underground railway enclosures was realized to identify the existing methodologies.

Three different scenarios were identified in order to achieve the different objectives sought through measurement campaigns: Short- and long-term measurement campaigns and measurements to assess the efficiency of air treatment systems in a station. The two first methodologies are described in this report.

Paragraph 7 discusses the inventory and potential of low-cost sensors for PM monitoring, specially targeting fine particulate matter (PM) measurement. It highlights the opportunity presented by these sensors to enhance air quality monitoring network due to their affordability and flexibility. Careful consideration must be given to their accuracy, reliability and the calibration process to ensure the data they provide is useful for making informed decisions about air quality management and public health. A calibration process has been described and some tests have been realized to calibrate and evaluate the identified low-cost sensors.

Paragraph 8 deals with the development of models for predicting particulate concentrations in underground railway stations (URS). A multi-factor model was developed by KTH to predict air pollution levels (PM1, PM2.5 and PM10) by utilizing over 2 years of long-term measurement data from one station in Stockholm, incorporating factors such as passenger flow, tunnel ventilation condition, urban background air pollution levels (mass concentrations of PM10, PM2.5, PM1), and nighttime maintenance activities. Additionally, a random forest model was developed by SNCF, based on air quality measurements on a station in Paris and on meteorological parameters (including rainfall, windspeed…), train frequency and train types, as well as outdoor pollutant concentrations.

24. Executive Summary D26.1 - User experience and User Interfaces, Knowledge and pre-concepts intermediate report n°1

The interiors are based on a fixed layouts for passengers with a limited range of adaptation. The Sub-project SP6 Attractiveness is integrated in the European Research Program Rail4EARTH dedicated for designing the most sustainable railway system, the members mix operators and manufacturers.

The objective of the Subproject SP6 is to reinforce train attractiveness for passengers, to stimulate modal transfer and to design train interiors with integrating the circular economy.

The objectives of the WP26 are to build new experiences on board considering the state of the art and the new

opportunities for the railway sector; to propose pre-concepts of new architecture of train specifically designed for ultramodularity by rethinking the integration of a toilet anywhere-anywhen without impacting the carbodyshell or to evolve a dedicated space like the driver's cabin to increase passengers capacity by new sizing, new positioning or new free space offer by a full autonomous operation years after the first commercial operation and propose pre-concepts of new user interfaces by using new technologies like contactless or voice control or the opposite way by using lowtech for few functions to limit the obsolescence. The WP will develop concept from the ideation phase to the feasibility studies. The development phase will be done with 2 main topics separately: new architectures for ultra-modularity and new user interfaces.

The deliverable D26.1 is dedicated to prepare the ideas with the state of the art of the partners and first main opportunities identified : for example, reduce the time to market, limit the risk of obsolescence, help to integrate new modules or carry-over of existing modules and an full hygienic interiors by a touchless design.

The main results of the first tasks of the project will be presented :

- A crossed state of the art from operators and carbuilders to define the main issues of the current design : for example the time to market too long, the obsolescence of technology not aligned with the main step of maintenance, the demand to increase passengers capacity in carbodyshell with limits of design (length, width and height) or the customisation without a full redesign of the interior's module.
- First challenges identified to select and develop during the design phase : for example the challenge of modular toilet, customisation instead of full redesign or architecture designed for capacity.