Deliverable D2.1

European Rail Research Themes and Funds

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1 Executive Summary

This document presents the methodology followed to complete the Task 2.1 *Scientific observatory for the ERJU actions* as well as its results.
Through a detailed study and synthesis of past and ongoing research activities, this deliverable will established a database and analytical framework that would form the core of the proposed scientific observatory.
The observatory's architecture will continuously monitor, evaluate, and integrate the most recent scientific and technological advancements in the rail sector in order to maintain research efforts in harmony with the ERJU's overarching goals.
The methodology includes the review of Shift2Rail MAWP, calls for proposals, project deliverables, intermediate and final assessment reports, followed by analysis of technical documents generated and continued with the synthesis of the previous 2 steps. The aim of this Task is to setup the observatory following these steps:

***Review of Shift2Rail Outputs**: This includes evaluating the Multi-Annual Work Plan (MAWP), calls for proposals, project deliverables, and both intermediate and final assessment reports. The focus is on identifying achievements that significantly advance the knowledge frontier and improve the performance of rail-based transport systems. This encompasses current successful implementations and future-oriented scientifically significant public deliverables and publications.*

***Analysis of Migration Documents from Shift2Rail to ERJU**: This involves examining the technical documents generated during the transition from Shift2Rail to ERJU, culminating in the ERJU Multi-Annual Work-Plan. The analysis emphasizes the establishment of a comprehensive rail systems knowledge foundation, drawing from Shift2Rail's Pillars and Innovation Programs (IP) and integrating the Flagship Areas of ERJU.*

***Synthesis and Roadmap Development**: This step combines insights from the reviews and analyses to create a framework for a scientific observatory that will be continuously updated with new scientific progress. It also involves developing a roadmap to track advancements beyond the current state of the art and plan future steps toward achieving the ultimate goals of ERJU.*

Through the creation of a robust database and analytical framework, this task sets the foundation for a scientific observatory to monitor and guide future research.

Shift2Rail has made notable progress in rail technology by improving interoperability, cost-efficiency, and sustainability, particularly through its structured Innovation Programs (IPs). As Shift2Rail transitions into ERJU, the focus has expanded to embrace emerging technologies like AI, IoT, and Big Data, while addressing automation, green initiatives, and intelligent asset management.

However, gaps remain, particularly in advancing research outputs to higher technology readiness levels (TRLs) and ensuring continuity in funding and partner involvement. To maintain momentum, the program should focus on commercializing innovations, expanding digitalization, and fostering stronger collaboration between SMEs, academia, and industry.

The development of the proposed scientific observatory will be instrumental in tracking progress and guiding future efforts, helping the European rail system stay at the cutting edge of global innovation. This initiative will also help realize the Single European Rail Area (SERA) by promoting a more efficient, reliable, and sustainable rail network.

2 Abbreviations and acronyms

A4R	Academics4Rail
AI	Artificial Intelligence
ATC	Automated Train Control
ATO	Automated Train Operation
CBA	Cost-Benefit Analyses
CCA	Cross-cutting activities
CCS	Control Command and Signalling
DAC	Digital Automatic Coupler
DOI	Digital Object Identifiercatory
EC	European Commission
ERA	European Union Agency for Railways
ERJU	Europe's Rail Joint Undertaking
ERMTS	European Rail Traffic Management System
ERRAC	European Rail Research Advisory Council
EU	European Union
EURNEX	EUropean Rail Network of EXcellence
FA	Flagship Area
FP	Flagship project
GEN	Università di Genova
GNSS	Global Navigation Satellite Systems
GOA4	Grade of Automation 4
H2020	Horizon 2020
IC	Innovation Capabilities
IoT	Internet of Things
IP	Innovation Program
KPIs	Key Performance Indicators
KTH	Kungliga Tekniska Högskolan
MaaS	Mobility as a Service
MAWP	Multi-Annual Work Programme
ML	Machine Learning
MM	Man Month
PPP	Public-Private Partnership
R&I	Research and Innovation
RFID	Radio Frequency Identification
ROM	Sapienza Università di Roma
RTO	Research and Technology Organisation
S2R	Shift2Rail
SME	Small and Medium-sized Enterprises
SUP	Scuola Universitaria Professionale della Svizzera Italiana
SWL	Single Wagon Load
TD	Technology Demonstrator
TL	Train Load
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability

3 Description of the Project

Academics4Rail is a stable and durable scientific community that in an organized way can share and exchange scientific knowledge with ERJU and ERRAC.

This knowledge is shared at different levels (strategic to concrete technical areas) and for different purposes. When it comes to the strategic level the scientific community intends to share knowledge with ERRAC and ERJU with the purpose of optimise the program for railway research providing insights of fund use, existing themes for research and scientific necessities for the future of European railways. It also supports the methodology of program assessment using KPIs and impact estimation towards the objectives set out in the ERJU masterplan. Finally, the scientific community shares its knowledge about necessities of future PhD funding with a relevant European and scientific weight.

In a more concrete technological domain, the scientific community engages in specific themes creating 6 PhD positions that will enlarge the knowledge in 6 specific areas and will enable the cooperation of academia with industry. The areas are:

1. PhD1 Aerodynamics of freight trains,
2. PhD2 Electromagnetic compatibility,
3. PhD3 Additive Manufacturing in wheel reprofiling,
4. PhD4 Digital communications for virtual coupling,
5. PhD5 Prognostics and health management approach for railway asset maintenance,
6. PhD6 Driving assistance.

4 Scope of the Task and intended audience

To identify significant knowledge gaps not addressed by the current MAWP, WP2 of A4R aims to establish an observatory of previous, existing, and planned research efforts in Shift2Rail and ERJU. The identification of future themes for academic research will be based on discovering these gaps.Together with ERRAC and the ERJU, the project will define a more structured framework to involve the academic community in the process of converting the high-level MAWP of the ERJU into proposals for pertinent research activities and to identify potential research needs not currently addressed by the MAWP.

5 Methodology

The methodology followed to accomplish the above-mentioned goals includes 3 steps which are described below.

Step 1: Review of the Shift2Rail MAWP, calls for proposals, project deliverables, intermediate and final assessment reports, with reference to accomplishments that can lead to quantifiable advances in knowledge and possible enhancements of rail-based transport systems' performances, both now, through successful implementation actions, and in the future, through publications and deliverables that are relevant to science.

Step 2: Analysis of technical documents generated during the transition from Shift2Rail to ERJU and up to the ERJU MAWP, with a focus on the establishment of a rail systems knowledge base, beginning with IP and pillars in Shift2Rail and the ERJU Flagship Areas.
The information has been initially collected by the templates described in chapter 6 filled in by the project partners after a careful search of the required information. Thereafter, the information has been double checked, homogenized and carefully analyzed

Step 3: Synthesis of steps 1 and 2 to create a scientific observatory architecture that is updated with scientific advancements on a regular basis, as well as a roadmap for tracking steps beyond the state of the art and planning future steps towards the ultimate goals of ERJU Remark – Artificial intelligence, Machine Learning, Internet of Things and big data analytics will be the focus of particular actions, such as technologies for autonomous driving and predictive maintenance, which have already been addressed in past and current Shift2Rail projects, such as RAILS, SMART, IN2RAIL, ATTRAKTIVE, IN2SMART, TAURO, etc.

To collect the above information, the following assignments were made to the partners:
Public information source from Shift2Rail**:**

1. MAWP **(BEL)**

Calls for proposals + Projects + Public Deliverables:

2. IP1: Cost-efficient and reliable trains **(ZGR)**
3. IP2: Advanced traffic management and control systems (**ZGR)**
4. IP3: Cost Efficient and Reliable High-Capacity Infrastructure (**BEL)**
5. IP4: IT Solutions for attractive railway services (GEN)
6. IP5: Technologies for sustainable and attractive European rail freight **(DLR)**
7. (IP6): Cross-cutting themes and activities (**CER)**
8. Actions addressing artificial intelligence, machine learning and big data analytics, such as technologies for autonomous driving and predictive maintenance (projects RAILS, SMART, IN2RAIL, ATTRAKTIVE, IN2SMART, TAURO) (**SUP)**

Public information sources from ERJU

1. MAWP **(KTH)**

Calls for proposals + Projects + Public Deliverables

2. FA1: Network management planning and control & Mobility Management in a multimodal environment (**GEN)**
3. FA2: Digital & automated up to Autonomous Train Operations **(CER)**
4. FA3: Intelligent & Integrated asset management **(GEN)**
5. FA4: A sustainable and green rail system **(CER)**
6. FA5: Sustainable Competitive Digital Green Rail Freight Services (**DLR)**
7. FA6: Regional rail services / Innovative rail services to revitalize capillary lines (**KTH)**
8. FA7: Innovation on new approaches for guided transport modes **(GEN)**

9. (FA8): Transversal Topic: Digital Enablers (**ROM)**
10. (FA9): Exploratory Research and other activities) **(CER)**
11. Actions addressing artificial intelligence, machine learning and big data analytics **(SUP)**

6 Data Collection Templates

The templates for the collection of the information are related to *Call for proposal, Projects and Deliverables* for both Shift2Rail and ERJU. These are reported below.

Table 1-Template Shift2Rail-Call for proposal

SHIFT2RAIL Call for proposals	
Topic	
Specific challenge	
Scope	
Expected impact	
Type of action	

Table 2-Template SHIFT2RAIL Project Deliverables

SHIFT2RAIL Project Deliverables	
Project Title (acronym)	
Topic	
Grant Agreement	
Title	
Due date	
Actual submission date	
Responsible/Author	
Contents	
Number of pages	
Executive summary	

Table 3-Template SHIFT2RAIL Projects

SHIFT2RAIL Projects	
Project Title (acronym)	
Topic	
Period	
Project value (EUR)	
IP	
Status	
Targeted TRL	
Objectives	
Structure	
Partners	
Results & Publications	

Table 4-Template ERJU Call for proposals

ERJU Call for proposals	
Topic	

Expected outcome	
Scope	
Type of action	

Table 5-Template ERJU Project Deliverables

ERJU Project Deliverables	
Project Title (acronym)	
Topic	
Grant Agreement	
Title	
Due date	
Actual submission date	
Responsible/Author	
Contents	
Number of pages	
Executive summary	

Table 6-Template ERJU Projects

ERJU Projects	
Project Title (acronym)	
Topic	
Grant Agreement	
Period	
Project value (EUR)	
FP	
Status	
Targeted TRL	
Objectives	
Structure	
Partners	
Results & Publications	

7 Analysis and Results of the Data Collected

7.1. The Shift2Rail Joint Undertaking

The Shift2Rail Joint Undertaking (S2R) is a public-private partnership in the rail sector established under Article 187 of the Treaty on the Functioning of the European Union, providing a platform for the rail sector to work together with a view to driving innovation in the years to come.
The objective of the ERJU, building upon S2R's achievements, is to deliver a high-capacity integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, covering traffic management, vehicles, infrastructure and services. This should exploit the huge potential for digitalization and automation to reduce rail's costs, increase capacity, enhance its flexibility and reliability, and should be based upon a solid reference functional system architecture shared by the sector, in coordination with the European Union Agency for Railways (ERA).

The primary task of the S2R was to establish the priority Research & Innovation (R&I) activities to accelerate the penetration of integrated, interoperable, and standardized technological innovations to support the Single European Railway Area (SERA) and to achieve operational excellence of the railway system. Research activities with impact on ERA activities, e.g. the technical specifications for Interoperability (TSIs), vehicle authorisations, safety certification, are always performed in close cooperation with ERA.

In addition, its main objective is to implement the S2R Programme and R&I activities in the railway sector in Europe, through the collaboration between stakeholders of the entire railway value chain, also outside the traditional rail sector, with particular attention to Small and Medium-sized Enterprises (SMEs), research, technology centres and universities.

The S2R Master Plan outlines the main strategic priorities with a vision extending to 2030, covering R&I activities beyond the S2R program's timeframe. It proposes a holistic approach of the rail system that takes into consideration the relevant railway subsystems and actors, as well as their complex interaction. It details which innovative solutions resulting from Technology Demonstrators (TDs) deliver the Innovation Capabilities (ICs). The TDs are organized in the following Innovation Programmes (IPs):

7.1.1. Innovation Programme 1 (IP1): Cost-efficient and Reliable Trains

The design of rolling stock is crucial for making rail transport appealing. Trains must be comfortable, reliable, affordable, and accessible to encourage passengers to choose rail over other transportation modes. Additionally, train design must satisfy the needs of railway companies and urban operators, who are the primary clients of the rail supply industry, to provide high-quality and cost-efficient services.
To better integrate with other transportation modes and attract more passengers, enhancing rail's role as the backbone of future multi-modal mobility, the next generation of passenger trains needs to be lighter, automated, and more energy and cost-efficient. These trains must also offer a comfortable, connected, reliable, and affordable travel experience, ensuring a defined level of safety and security for all passengers.
The S2R identified the following priority research and innovation areas in which activities should be undertaken with a view to achieving the ambition of IP1:

- Traction,
- Train Control and Monitoring System,
- Car body shell,
- Running Gear,
- Brakes,
- Doors and Intelligent access systems,
- Train interiors,

- Heating, Ventilation and Air Conditioning (HVAC).

Important areas of attention are those concerning noise and human factors, covered by Cross-Cutting Activities (CCA). This IP has a significant contribution and a link with the Command Control and Signalling (CCS) systems, in cooperation with IP2.
Table 7 shows the research projects that are part of this programme.

Table 7-Research projects in Shift2Rail IP1

Project Title (acronym)	Period		Budget (euro)
PINTA	01/09/16	31/12/18	12.823.244
CONNECTA	01/09/16	30/09/18	5.477.520
SAFE4RAIL	01/10/16	31/12/18	6.681.211
RUN2RAIL	01/09/17	30/09/19	2.732.464
MAT4RAIL	01/10/17	30/09/19	3.495.216
PIVOT	01/10/17	31/12/19	7.746.802
PINTA2	01/09/18	28/02/21	28.534.184
SAFE2RAIL2	01/10/18	31/07/21	3.991.633
CONNECTA-2	01/10/18	31/07/21	9.687.622
PIVOT2	01/10/19	31/03/23	40.155.405
NEXTGEAR	01/12/19	28/02/22	2.573.878
CARBODIN	01/12/19	28/02/22	3.334.368
GEARBODIES	01/12/20	30/06/23	2.419.969
PINTA3	01/12/20	31/05/23	19.242.343
CONNECTA-3	01/12/20	31/07/23	8.973.663
RECET4RAIL	01/12/20	30/09/23	2.300.036
SAFE4RAIL-3	01/12/20	31/07/23	6.132.399

The programme benefited from a budget of EUR 166,301,956, and as can be deduced from the figures in the table, the IP1 Traction TD1 and Brakes TD5 (PINTA) and Performance Improvement for Vehicles on Track (PIVOT) projects, which accounted for 65% of the funds, have a significant weight.
Considering the starting year of the above-mentioned projects, it is observed that there was a budget reduction from 2016 to 2017 and a substantial increase in the following years, followed by from 2019 to 2020 there was a decrease (Figure1).

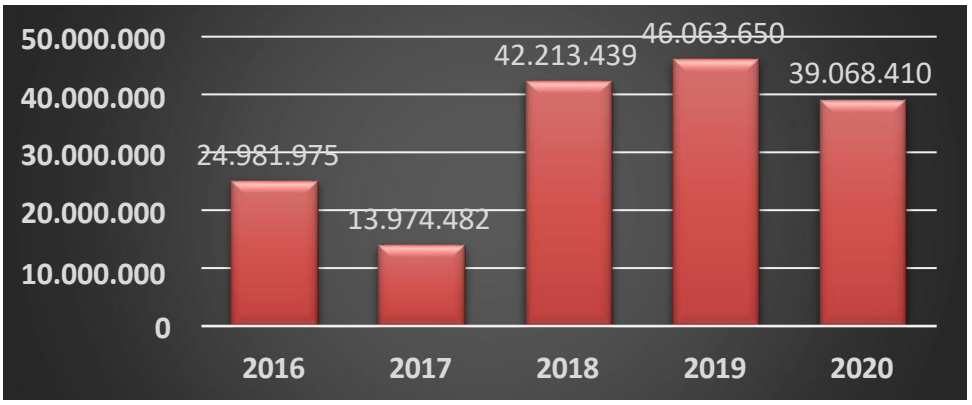


Figure 1-Research budget allocated per year in IP1

A similar trend can be observed if we also consider the number of partners per project and report the average budget per partner for each starting year (Figure 2).

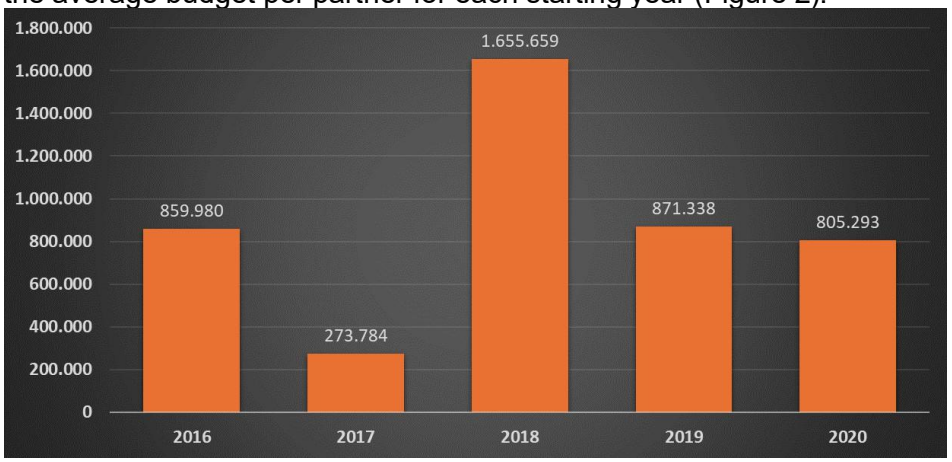


Figure 2-average research budget per partner in IP1

In addition, considering the duration of the projects (expressed in numbers of months), we report the average budget by cumulating the projects by the year of commencement.

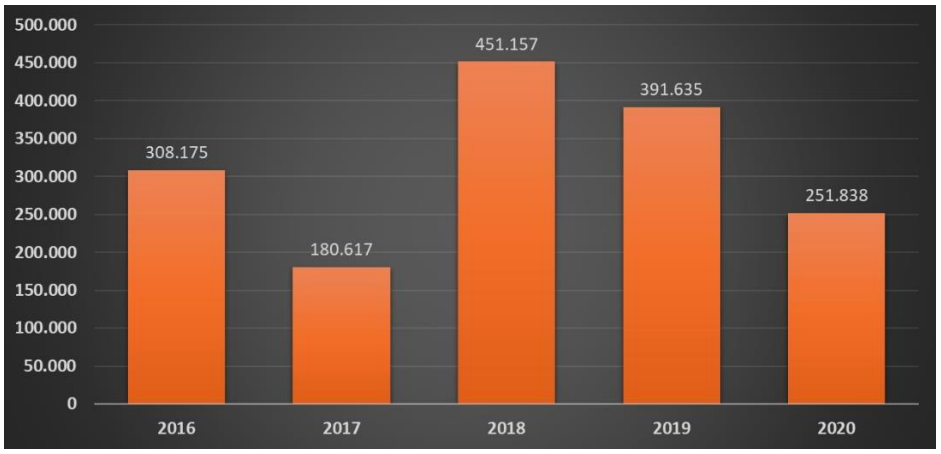


Figure 3-average research budget per month per project starting year in IP1

7.1.2. Innovation Programme 2 (IP2): Advanced Traffic Management and Control Systems

Control, command, and communication systems should evolve from merely ensuring the control and safe separation of trains to becoming a flexible, real-time, intelligent, integrated, and fully automated traffic management system. While the European Rail Traffic Management System (ERTMS) is already the leading global solution for railway signalling and control, it has the potential to offer even more functionalities and become more competitive.

Current systems do not fully utilize new technologies and practices, such as satellite positioning, high-speed and high-capacity data and voice communication systems (Wi-Fi, 5G, and future generations), automation, and innovative real-time data collection, processing, and communication. These advancements could lead to new traffic management concepts, resulting in improved capacity, reduced traction energy consumption and carbon emissions, lower operational costs, enhanced safety and security, and better customer information.

The S2R Master Plan identifies seven priority research and innovation areas in which activities should be undertaken with a view to achieving the ambition of IP2:

- Smart, fail-safe communications and positioning systems,
- Traffic management evolution,
- Automation,
- Moving Block (MB) and train integrity,
- Smart procurement and testing,

- Virtual coupling,
- Cyber security.

Important areas of attention are those concerning human factors (covered by CCA) and the link with shared train equipment, in cooperation with IP1. Since 2019, the Programme integration, regarding the IP2 activities, has also been ensured by a new stream of work (IPx) dedicated to the functional system architecture to be derived from a sector shared vision on future rail operations.
Table 8 shows the research projects that are part of this programme.

Table 8-Research projects in Shift2Rail IP2

Project Title (acronym)	Period		Budget (euro)
IN2RAIL	01/05/15	30/04/19	18.000.000
In2Rail	01/05/15	30/04/18	18.000.000
X2Rail1	01/09/16	30/06/21	18.090.999
CYRAIL	01/10/16	30/09/18	1.498.150
VITE	01/11/16	31/12/18	947.757
MISTRAL	01/11/16	31/10/18	499.283
ETALON	01/09/17	29/02/20	1.699.999
ASTRail	01/09/17	31/10/19	1.797.308
X2rail2	01/09/17	30/04/21	13.399.917
GATE4RAIL	01/12/18	28/02/21	1.019.994
MOVINGRAIL	01/12/18	31/12/20	1.299.135
EMULRADIO4RAIL	01/12/18	31/12/20	748.098
X2Rail3	01/12/18	30/11/21	38.728.459
OPTIMA	01/12/19	28/02/23	2.235.999
4SECURAIL	01/12/19	30/11/21	549.875
X2Rail4	01/12/19	28/02/23	41.109.700
PERFORMINGRAIL	01/12/20	30/06/23	1.335.359
X2RAIL5	01/12/20	31/10/23	33.890.375
AB4Rail	01/01/21	31/12/22	349.926

The available budget was EUR 195,200,331, with the projects' activities for Adaptable Communication, Moving Block, fail safe Train Localisation (including satellite), Zero on-site Testing, Formal Methods and Cyber Security (X2RAIL) accounting for 74% of the funds.
Figure 4 shows the budget figures for IP2 for the period 2015 to 2021.

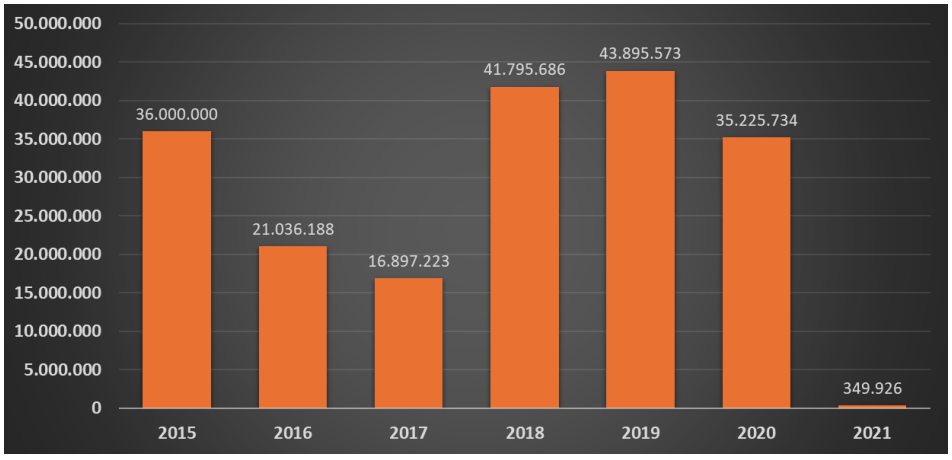


Figure 4-Research budget allocated per year in IP2

In addition, considering the duration of the projects (expressed in numbers of months), the average budget by cumulating the projects by starting year is reported in Figure 5

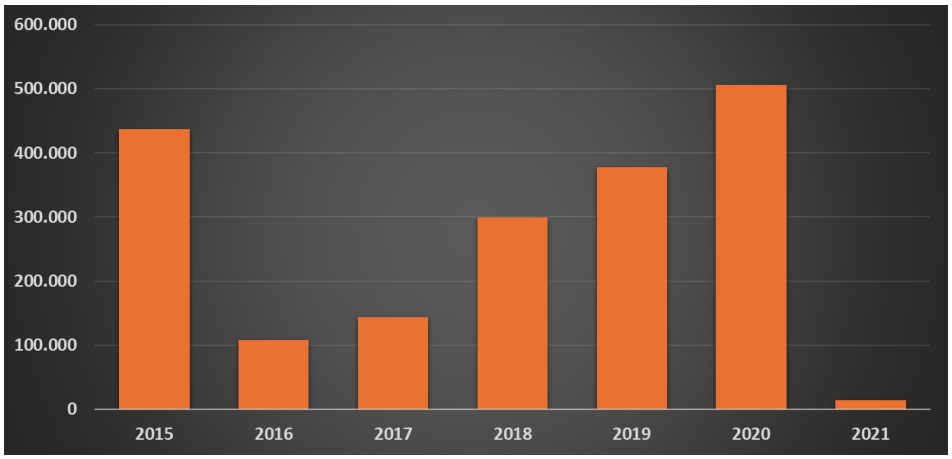


Figure 5-average research budget per month in IP2

In figure 6, the development of the average budget per partner for each starting year is shown.

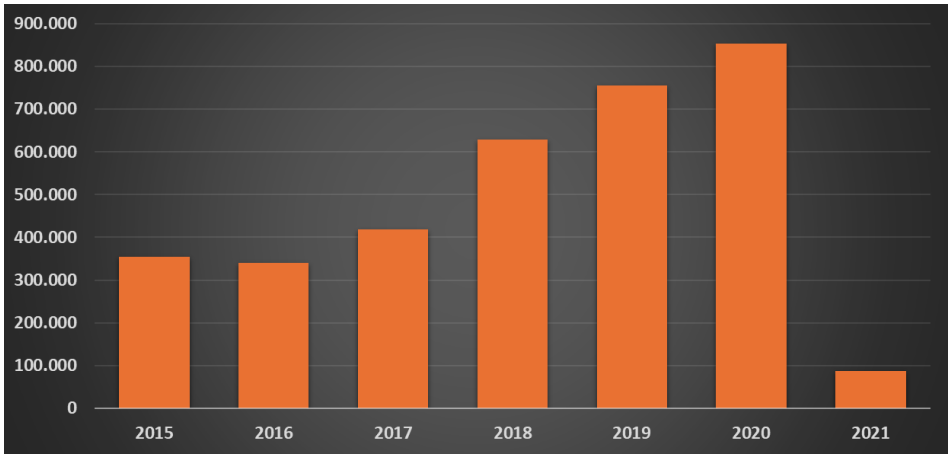


Figure 6-average research budget per partner cumulated per project starting year in IP2

7.1.3. Innovation Programme 3 (IP3): Cost-efficient and Reliable High-Capacity Infrastructure

The design, construction, operation, and maintenance of rail network infrastructure must be safe, reliable, customer-focused, cost-effective, and sustainable. To achieve the benefits of market opening and interoperability while reducing the life-cycle costs of rolling stock and onboard signalling systems, network diversity needs to be eliminated, primarily through a shift towards a common, high-performing infrastructure system architecture.

Priority should be given to activities that can lower infrastructure maintenance costs, such as simplified procedures or automation, by proposing solutions that can be rapidly and efficiently implemented. Additionally, infrastructure management should be more holistic and intelligent, incorporating lean operational practices and smart technologies to enhance the reliability and responsiveness of customer service, as well as the capacity and overall economics of rail transportation.

Ensuring compatibility between different elements of cross-modal transport infrastructure, such as multimodal hubs, charging points, and stations, is essential and should be based on principles of interoperability and standardization.

The six priority areas in which activities should be undertaken with a view to achieving the ambition of IP3 are:

- New directions in switches and crossings,

- Innovative track design and materials,
- Cost-effective Tunnel & Bridge solutions,
- Intelligent system maintenance,
- Energy efficiency,
- Improved station concepts.

The available budget was EUR 136,637,343, with the Intelligent Innovative Smart Maintenance of Assets by integrated Technologies (IN2SMART) and Research into enhanced tracks, switches and structures (IN2TRACK) projects accounting for 75% of the funds (Table 9).

Table 9-Research projects in Shift2Rail IP3

Project Title (acronym)	Period		Budget (euro)
IN2SMART2	01/09/16	31/10/19	16.405.563
IN2TRACK	01/09/16	30/04/19	6.324.052
IN2SMART	01/09/16	31/10/19	16.405.563
S-CODE	01/11/16	31/10/19	4.999.771
IN2STEMPO	01/09/17	31/03/23	13.439.977
FAIR Stations	01/09/17	31/12/19	1.199.875
MOMIT	01/09/17	31/10/19	599.173
IN2DREAMS	01/09/17	31/10/19	2.195.715
IN2TRACK2	01/11/18	28/02/22	29.676.015
Assets4Rail	01/12/18	31/12/21	5.506.631
IN2SMART2	01/12/19	31/05/23	23.091.204
FUNDRES	01/12/19	30/11/21	749.540
DAYDREAMS	01/12/20	31/05/23	1.709.875
IN2ZONE	01/12/20	31/05/23	1.349.974
STREAM	01/12/20	31/05/24	2.700.000
IN2TRACK3	01/01/21	31/12/23	26.689.979

Figure 7 shows the budget figures for IP3 for the period from 2016 to 2021.

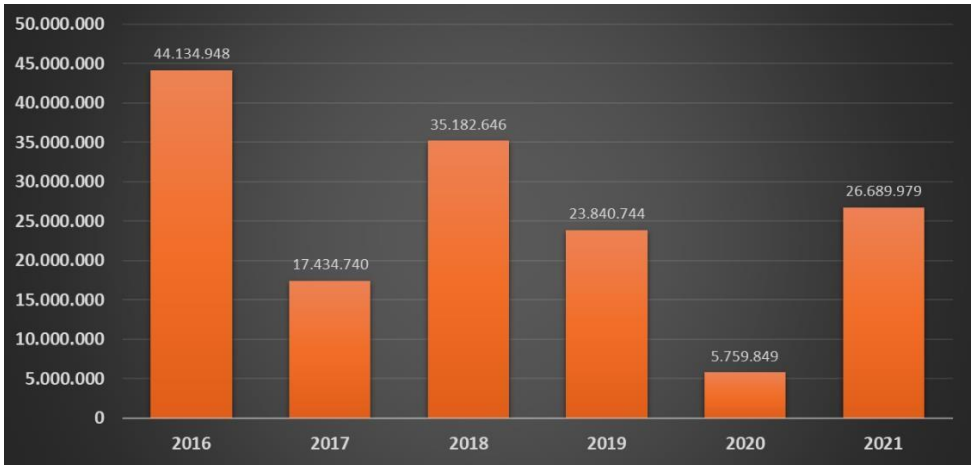


Figure 7-Research budget allocated per year in IP3

In Figure 8, considering the duration of the projects (expressed in numbers of months), we report the average budget by cumulating the projects by the starting year.
In addition, the development of the average budget per partner for each starting year is shown (Figure 9).

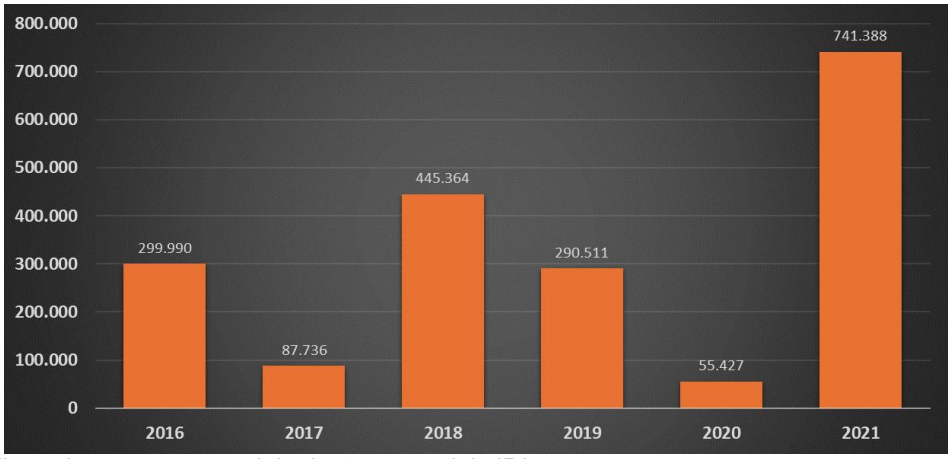


Figure 8 average research budget per month in IP3

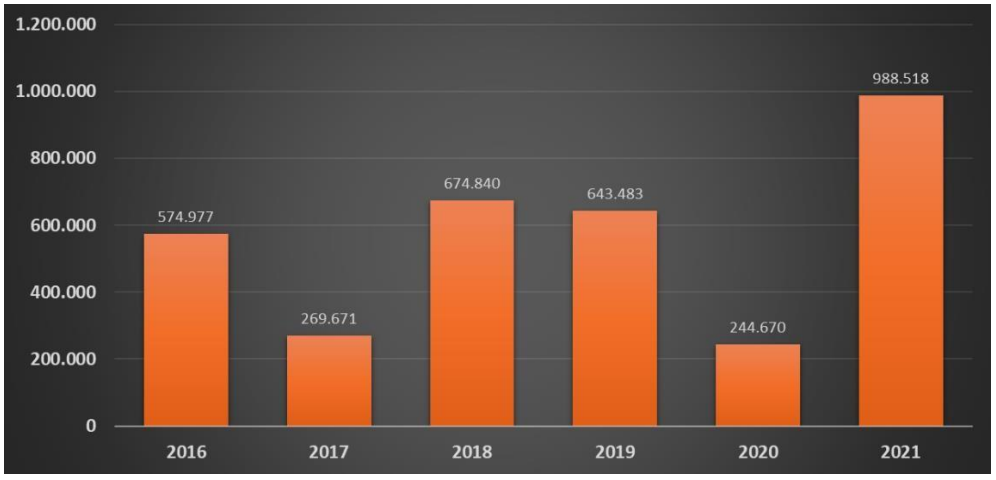


Figure 9-average research budget per partner cumulated per project starting year in IP3

7.1.4. Innovation Programme 4 (IP4): IT Solutions for Attractive Railway Services

To become more attractive, rail must meet customer needs by supporting seamless door-to-door multimodal journeys that encompass various modes of transport. Rail needs to achieve interoperability with other transport modes and mobility services across different regions, cities, and borders. This requires leveraging the growing connectivity of people and objects, the availability of the European Global Navigation Satellite System (GNSS) and other localization methods, advancements in cloud computing, Open Data, Big Data Analytics, and the widespread use of the Internet and social media. Existing rail standards like FSM and TAP TSI will also aid multimodal integration.
To achieve this, the IP4 ecosystem aims to integrate and make all transport modes and travel services interoperable. Initially, the Programme integrated rail, urban transport (metro, tram, and buses), and airlines. It then expanded to include transport services involving private cars (such as toll roads and parking) and shared modes (cars and bikes). This fosters multimodality and the use of public transport, making it easier for travellers to connect with rail stations and airports, regardless of their journey's starting point. In the future, Demand Responsive Transport and Ride Sharing will be included to enhance accessibility for everyone.
The IP4 Ecosystem has also evolved to implement the new Mobility-as-a-Service (MaaS) paradigm

at the European level, viewing the mobility system to achieve an optimal and sustainable transport scheme. This ecosystem facilitates creating formal contracts that involve agreements, business rules, and financial compensation between different stakeholders when combining their services into a joint product. In the future, this component will evolve to create MaaS Packages that integrate a

variety of transport services, including multiple Transport Service Providers.
The available budget was EUR 75,350,408 (Table 10).

Table 10-Research projects in Shift2Rail IP4

Project Title (acronym)	Period		Budget (euro)
IT2RAIL	01/05/15	30/04/18	12.025.000
CO-ACTIVE	01/09/16	31/05/19	7.621.915
ATTRACKTIVE	01/09/16	31/05/19	5.256.030
GOF4R	01/11/16	31/10/18	2.000.000
ST4RT	01/11/16	31/10/18	1.000.000
COHESIVE	01/09/17	31/12/22	4.039.491
CONNECTIVE	01/09/17	30/06/23	7.906.243
MY-TRAC	01/09/17	31/12/20	3.494.476
MaaSive	01/11/18	31/07/21	11.692.236
SHIFT2MAAS	01/12/18	30/06/21	1.499.906
SPRINT	01/12/18	28/02/21	1.999.500
RIDE2RAIL	01/12/19	30/04/23	2.999.994
IP4MAAS	01/12/20	31/05/23	2.507.081
EXTENSIVE	01/12/20	30/06/23	11.308.534

Figure 10 shows the budget figures for IP4 for the period from 2015 to 2020.

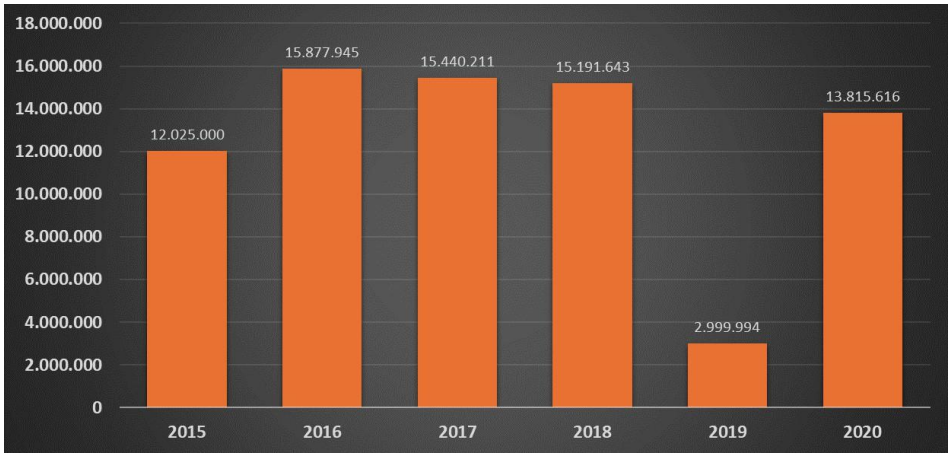


Figure 10-Research budget allocated per year in IP4

In Figure 11, we report the average budget by cumulating the projects by the starting year considering the duration of the projects (expressed in numbers of months).

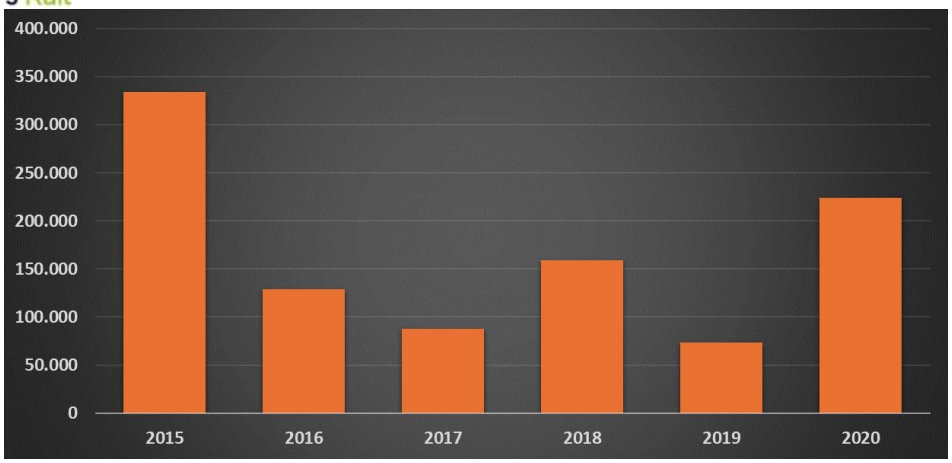


Figure 11-average research budget per month in IP4

In addition, the development of the average budget per partner for each starting year is shown. (Figure 12).

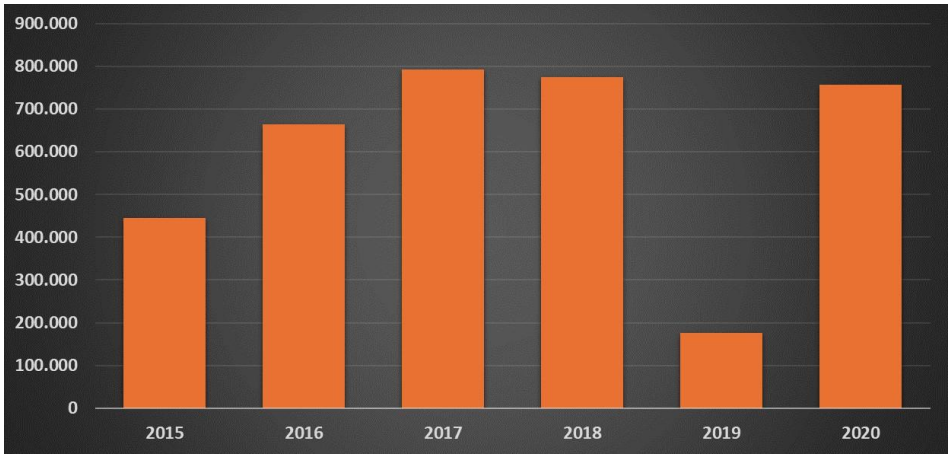


Figure 12-average research budget per partner cumulated per project starting year in IP4

7.1.5. Innovation Programme 5 (IP5): Technologies for Sustainable and Attractive European Rail Freight

To achieve the ambitious goals set in the Transport White Paper regarding rail freight development, including nearly doubling rail freight use compared to 2005 and shifting 30% of road freight over 300 km to rail or waterborne transport by 2030 (and over 50% by 2050), the cost competitiveness and reliability of freight services must be significantly improved. Rail freight needs to offer shippers cost-effective and attractive services, helping to reduce road congestion and becoming the backbone of the Union's inland integrated logistics system.

Identifying different market segments with specific technical and operational characteristics is essential to direct research and innovation towards current and future market needs. The first segment is intermodal transport, which relies on containers and trailer trains and is expected to continue growing. Improvements in train length utilization, innovative rolling stock features, terminal operations, real-time customer information, and data exchange using open standards (including TAF TSI) can enhance reliability, service quality, and cost competitiveness in this segment.

The second segment is wagonload activity, including Single Wagon Load (SWL) and Train Load (TL) services, which rely on specific freight wagons. SWL services have declined significantly in recent years, and realizing their growth potential requires substantial improvements in service quality and reliability. Solutions like automated coupling and decoupling and tagging all wagons with automatically readable Radio Frequency Identification (RFID) tags, can expedite train formation, reduce costs, and enhance the overall performance of wagonload services.

A high-value IT framework needs to be established to support all these areas. Ensuring co-modality and multimodality in freight mobility, i.e., linking to other freight modes, is crucial. Additionally, attention must be given to human factors, where the contribution of CCA and this IP is significant.
The available budget was EUR 78,399,514, with FR8RAIL projects accounting for 78% of the funds. Figure 13 shows the budget figures for IP5 for the period from 2016 to 2021.
Figure 14 we report the development of the average budget per month for each starting year, considering the duration of the projects (expressed in numbers of months).
In addition, we report the average budget per partner by cumulating the projects by the starting year of commencement (Figure 15).

Table 11-Research projects in Shift2Rail IP5

Project Title (acronym)	Periodo		Budget (euro)
SMARTRAIL	01/05/15	30/04/18	5.999.213
ARC	01/09/16	30/04/21	3.600.360
FFL4E	01/09/16	31/07/19	3.375.017
FR8RAIL	01/09/16	31/08/19	7.826.783
FR8RAIL	01/09/16	31/08/19	7.826.783
SMART	01/10/16	30/09/19	999.599
FR8RAILII	01/10/16	30/09/19	12.450.390
INNOWAG	01/11/16	30/06/19	1.500.563
DYNAFREIGHT	01/11/16	30/06/18	999.823
FR8HUB	01/09/17	28/02/21	9.900.990
OPTIYARD	01/10/17	30/09/19	999.599
Marathon2Operation	01/12/18	31/12/20	599.955
FR8RAILIII	01/09/19	30/06/23	13.061.601
LOCATE	01/11/19	30/04/22	1.499.073
Smart2	01/12/19	30/11/22	1.708.738
FR8RAILIV	01/07/20	31/03/23	17.705.028
DACCELERATE	01/06/21	31/12/22	2.171.998

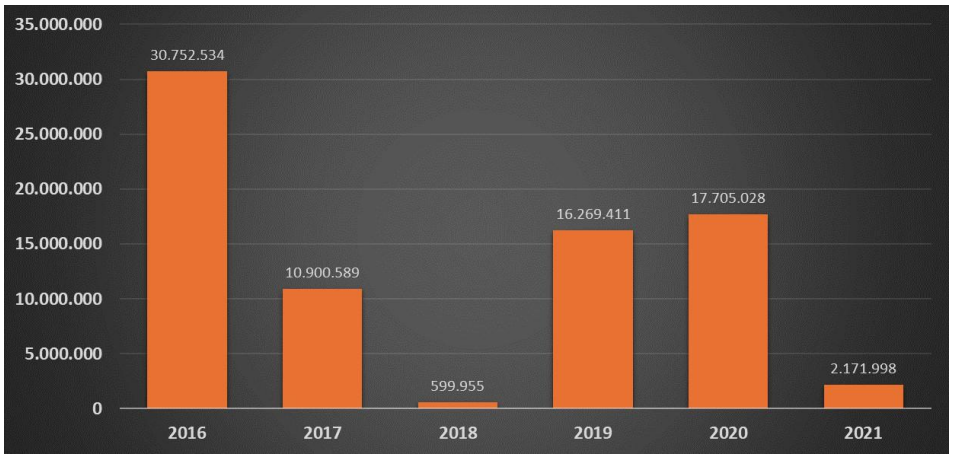


Figure 13-Research budget allocated per year in IP5

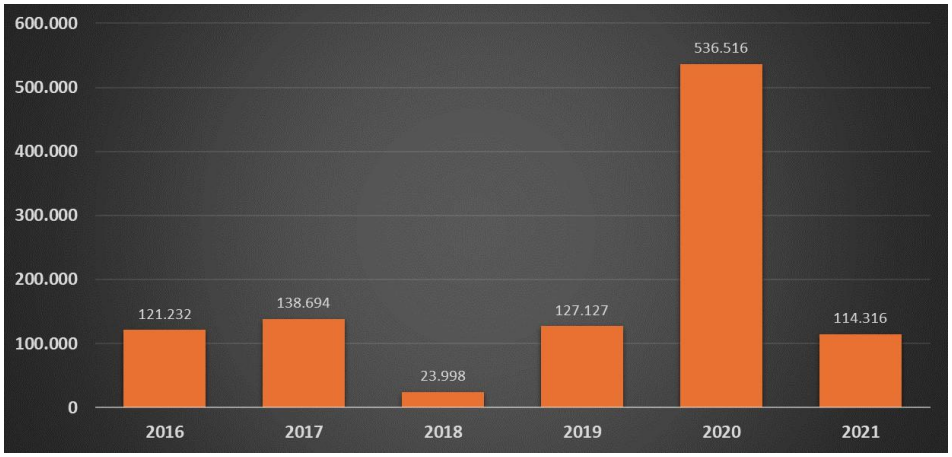


Figure 14-average research budget per month in IP5

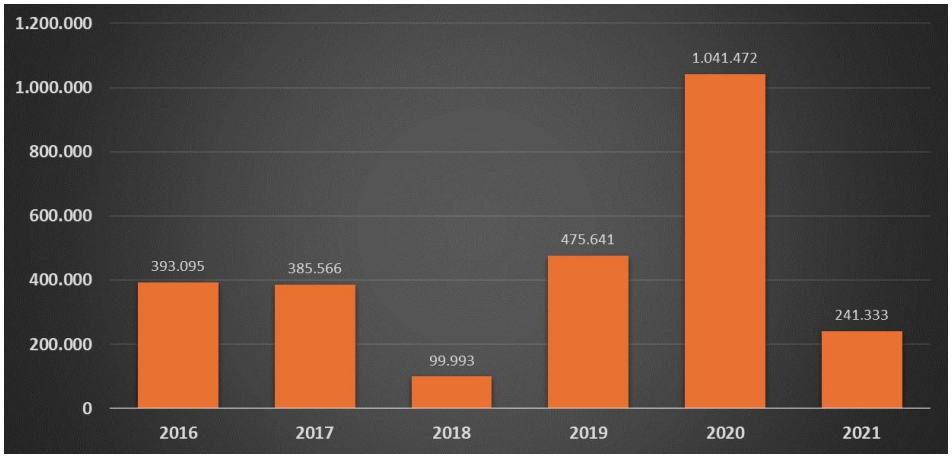


Figure 15-average research budget per partner cumulated per project starting year in IP5

7.1.6. Cross-Cutting Themes and Activities

In addition to the five Innovation Programmes, R&I activities will encompass CCA relevant to each subsystem and their interactions. These CCA activities will ensure that R&I efforts across the different Innovation Programmes are aligned in terms of objectives, requirements, and impact evaluation methodologies. They include elements within the Innovation Programmes that require horizontal coordination, such as energy and noise management, and additional R&I necessary to complement the technical work of the S2R. The S2R Master Plan identifies five priority research and innovation areas to achieve the CCA objectives:

- Long-term needs and socio-economic research.
- Smart materials and processes.
- System integration, safety, and interoperability,
- Energy and sustainability,
- Human capital.

Beyond the technical challenges addressed by IPs and CCA, market uptake of innovative solutions must address barriers, such as product acceptance, specific business case development, appropriate charging mechanisms, and standards for innovative products. The S2R concept aims to eliminate these barriers, supported by Cost-Benefit Analyses (CBA). Additionally, S2R activities will incorporate relevant work to prepare for future technical standardization and regulation of proposed innovations where applicable.

The available budget was EUR 68,572,342, with almost 50% of the resources going to the two projects IN2Rail and ROLL2RAIL (Table 12).

Figure 16 shows the data on the budgets directed to the CCA for the period from 2015 to 2021.
Figure 17, considering the duration of the projects (expressed in numbers of months), we report the average budget by cumulating the projects by the starting year of commencement.
In addition, Figure 18 reports the development of the average budget per partner for each starting year.
With the launch of the Linx4Rail project in 2019, followed by Linx4Rail2 in 2020, the S2R has officially dedicated research and innovation activities to developing a comprehensive functional system architecture. This architecture covers both safety and non-safety aspects, combining various railway subsystems with a modular approach and standard interfaces between key functional components, while preserving know-how and competitiveness. This will be fundamental in framing R&I results into a coherent, implementable system approach, driving the transformation towards an integrated and connected railway system. It will introduce a structured approach to the functional evolution of railway systems, involving S2R members and other actors not directly involved in the JU, leveraging progress from different stakeholder groups or companies. This effort aims to provide the sector with a unified vision for future rail operations, under the policy leadership of the European Commission and in close coordination with ERA.

Table 12-Research projects in Shift2Rail CCA

Project Title (acronym)	Period		Budget (euro)
In2Rail	01/05/15	30/04/19	17.998.546
ROLL2RAIL	01/05/15	31/10/17	16.000.000
SMARTRAIL	01/05/15	30/04/18	5.999.213
FINE-1	01/09/16	31/10/19	3.017.282
IMPACT-1	01/09/16	30/04/18	674.958
PLASA	01/09/16	31/08/18	786.349
GoSafeRail	01/10/16	30/09/19	1.298.750
NEAR2050	01/10/16	30/04/18	399.891
DESTINATE	01/11/16	31/10/18	1.271.813
OPEUS	01/11/16	31/10/19	797.130
IMPACT-2	01/09/17	31/12/22	7.096.428
SMaRTE	01/09/17	31/10/19	769.959
PLASA-2	01/09/18	31/12/20	1.853.348
FINE-2	01/12/19	31/05/23	8.179.973
TRANSIT	01/12/19	28/02/23	1.308.719
SILVARSTAR	01/11/20	28/02/23	950.000
Ben@Rail	01/09/21	31/05/22	169.985

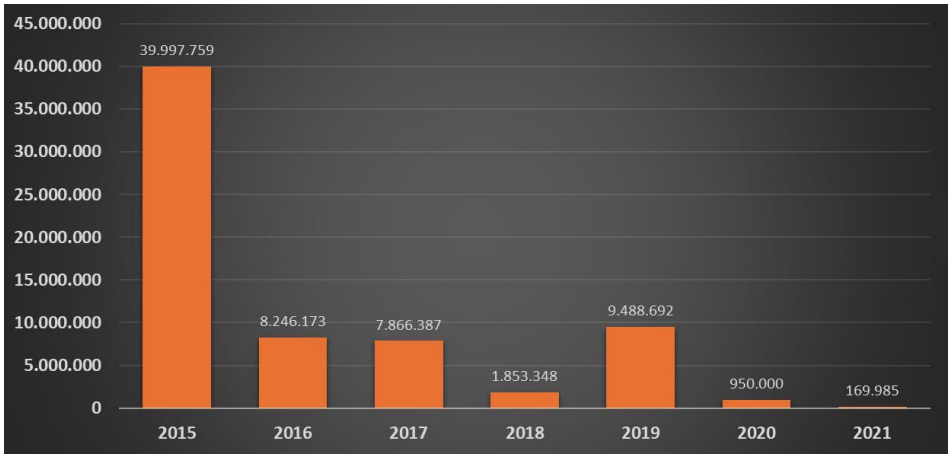


Figure 16-Research budget allocated per year to CCA

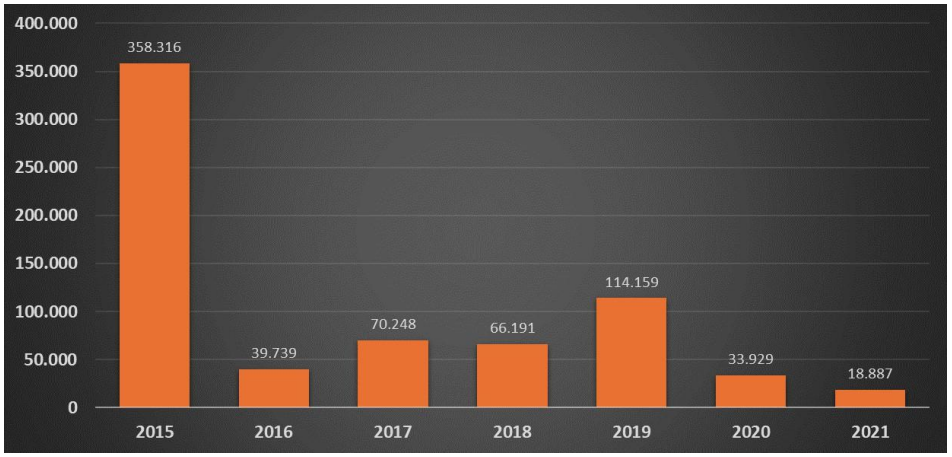


Figure 18-average research budget per month in CCA

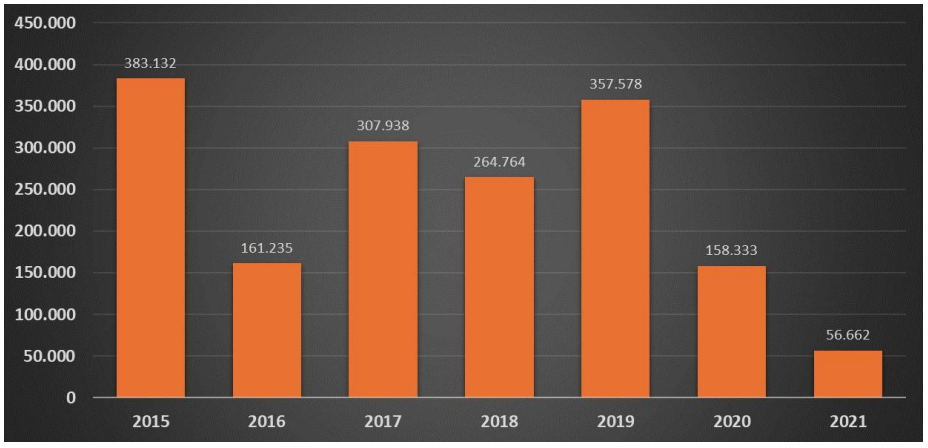


Figure 17-average research budget per partner cumulated per project starting year in CCA

Furthermore, IPx activities focus on emerging and non-traditional technologies and operational concepts, accelerating the development of new services for passengers and cargo. These projects are inherently *open*, primarily involving low TRL activities to explore the impact of new technologies and sciences, such as Blockchain, Artificial Intelligence, and Internet of Things, with a view towards their implementation in rail applications.
The available budget was EUR 15,650,894, with almost 50% of the resources going to the last two projects TAURO and LINX4RAIL2 (Table 13).

Table 13-Research projects in Shift2Rail IPx

Project Title (acronym)	Period		Budget (euro)
B4CM	01/12/18	30/11/22	124.951
FLEX-RAIL	01/12/18	30/06/21	1.099.230
TER4RAIL	01/12/18	30/11/20	499.993
MVDC-ERS	01/12/18	30/04/22	125.000
HYPERNEX	01/12/19	28/02/22	250.000
LINX4RAIL	01/12/19	30/11/22	5.216.494
RAILS	01/12/19	30/11/22	299.954
TRANSLATE4RAIL	01/12/19	30/11/21	248.094
LINX4RAIL2	01/12/20	31/05/23	3.227.376
TAURO	01/12/20	31/05/23	4.559.803

Figure 19 shows the data on the budgets directed to IPx for the period from 2018 to 2020.
In Figure 20, considering the duration of the projects (expressed in numbers of months), we report the average budget by grouping the projects by the year of commencement.
In addition, the development of the average budget per partner for each starting year is shown (Figure 21).

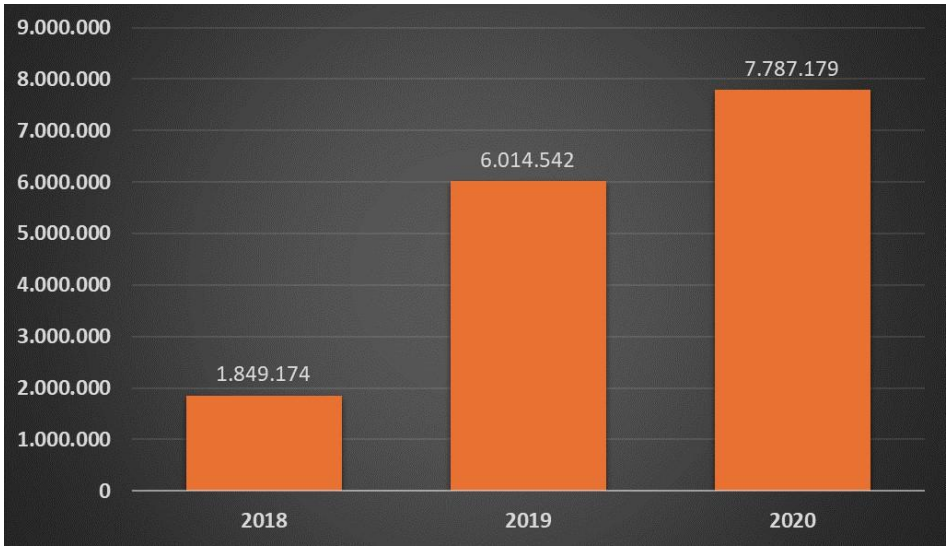


Figure 19-Research budget allocated per year to IPx

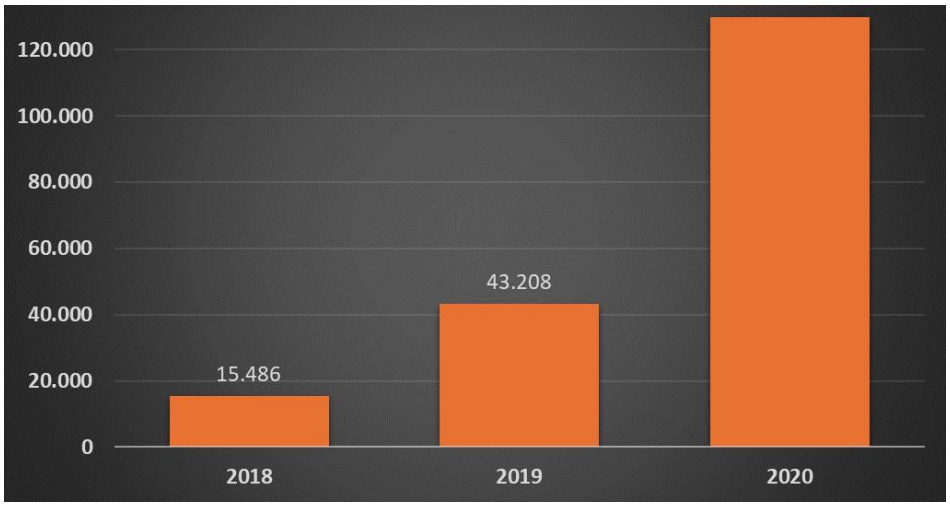


Figure 20-average research budget per month in IPx

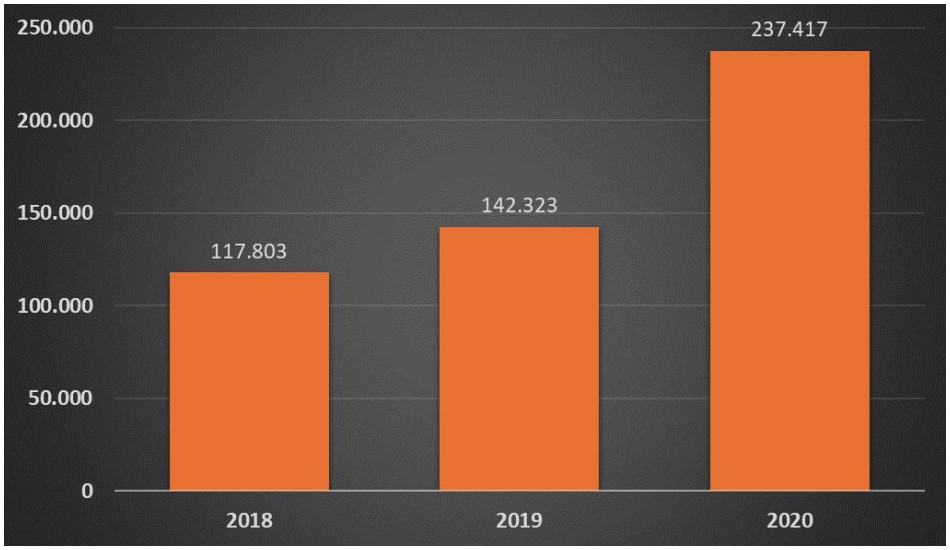


Figure 21-average research budget per partner cumulated per project starting year in IPx

7.1.8. Global Shift2Rail analysis

In total, the work described in the present Deliverable, considers 108 S2R projects (Table 14). Figure 22 shows the temporal distribution of S2R projects starting from 1 April 2015 to 1 September 2021. Considering the average monthly expenditure for all the S2R projects (Figure 23), the distribution is similar to a normal distribution, meaning that the larger budgets were invested in the middle of the control period.

Table 14-Distribution of S2R projects by year and IPs

	IP1	IP2	IP3	IP4	IP5	IPX	CCA
Projects 2021					DACCELERATE		BENRAIL
Projects 2020	CONNECTA-3 PINTA3 GEARBODIES RECET4RAIL SAFE4RAIL-3	X2RAIL-5 AB4RAIL PERFORMINGRAIL	IN2TRACK3 DAYDREAMS IN2ZONE STREAM	EXTENSIVE IP4MAAS	FR8RAIL IV	LINX4RAIL2 TAURO HYPERNEX	SILVARSTAR
Projects 2019	CARBODIN NEXTGEAR PIVOT2	4SECURAIL OPTIMA X2Rail-4	FUNDRES IN2SMART2	RIDE2RAIL	FR8RAIL III LOCATE SMART2	LINX4RAIL RAILS Translate4Rail	FINE-2 TRANSIT
Projects 2018	CONNECTA-2 PINTA2	X2Rail-3	In2Track2	MAASIVE	FR8RAIL II	B4CM FLEX_RAIL MVDC-ERS TER4RAIL	PLASA-2
Projects 2017	PIVOT Mat4Rail Run2Rail	X2Rail-2 ASTRAIL ETALON	In2Stempo IN2DREAMS Fair Stations MOMIT	Cohesive CONNECTIVE My-TRAC	FR8HUB OptiYard		IMPACT-2 SMaRTE
Projects 2015/2016	CONNECTA PINTA Safe4Rail	X2Rail-1 VITE CYRail MISTRAL	In2Track In2Smart S-Code	ATTRACkTIVE Co-Active ST4RT GOF4R	FFL4E FR8Rail ARCC SMART INNOWAG DYNAFREIGHT		IMPACT-1 PLASA FINE 1 NEAR 2050 GoSAFE RAIL DESTINATE OPEUS
Lighthouse Projects	Roll2Rail	(In2Rail) (Roll2Rail)	In2Rail	IT2Rail	Smart-Rail		(Smart-Rail) (Roll2Rail) In2Rail

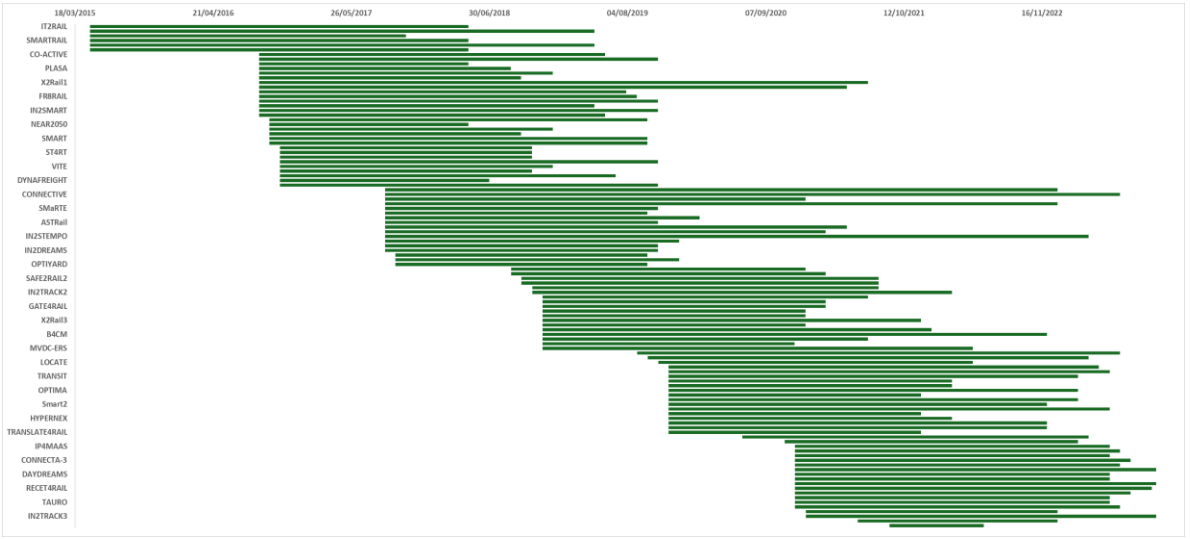


Figure 22-Temporal distribution of Shift2Rail projects

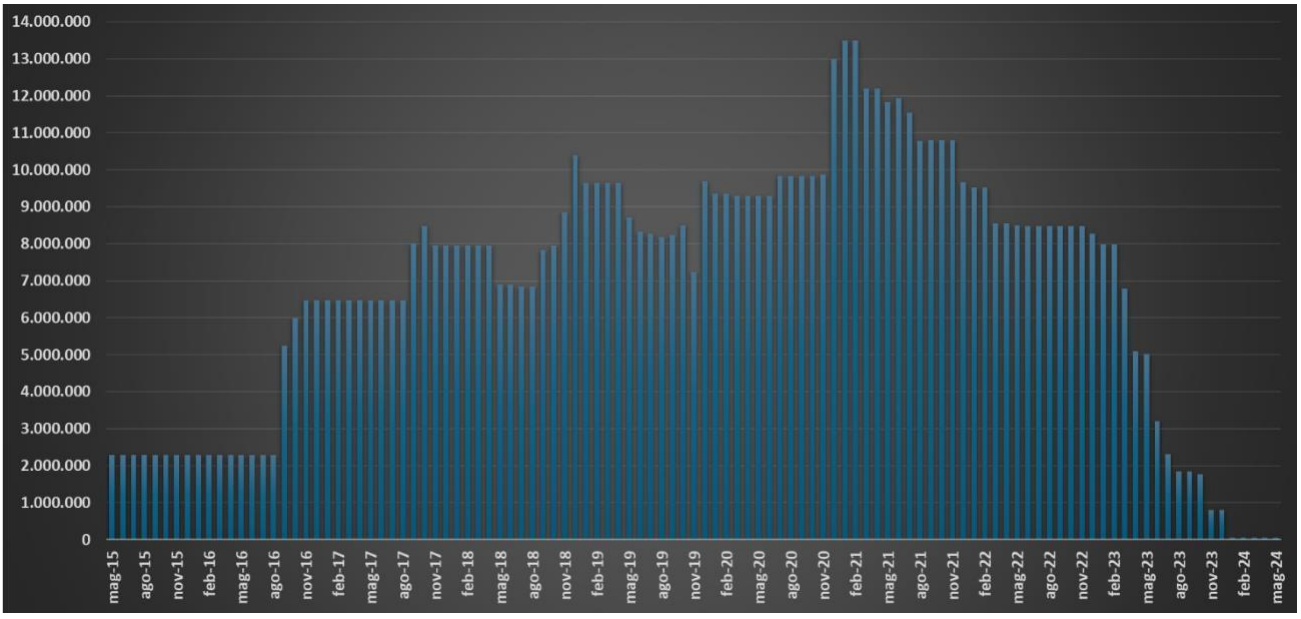


Figure 23-Research budget allocated per month to Shift2Rail projects

In addition, figures 24 and 27 show the sum and the percentual of the projects' budgets for each starting year.

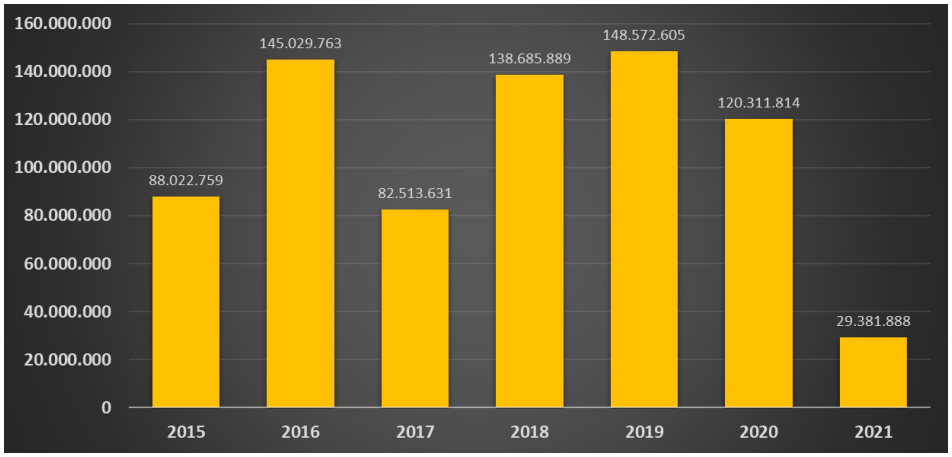


Figure 24-Research budget allocated per year to Shift2Rail projects

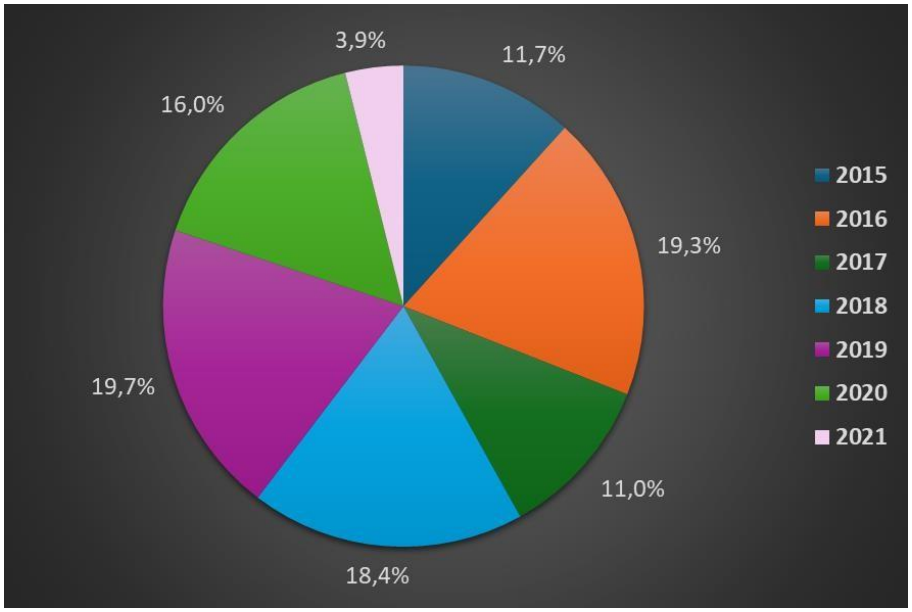


Figure 25-Percentual budget allocated per year to S2R projects

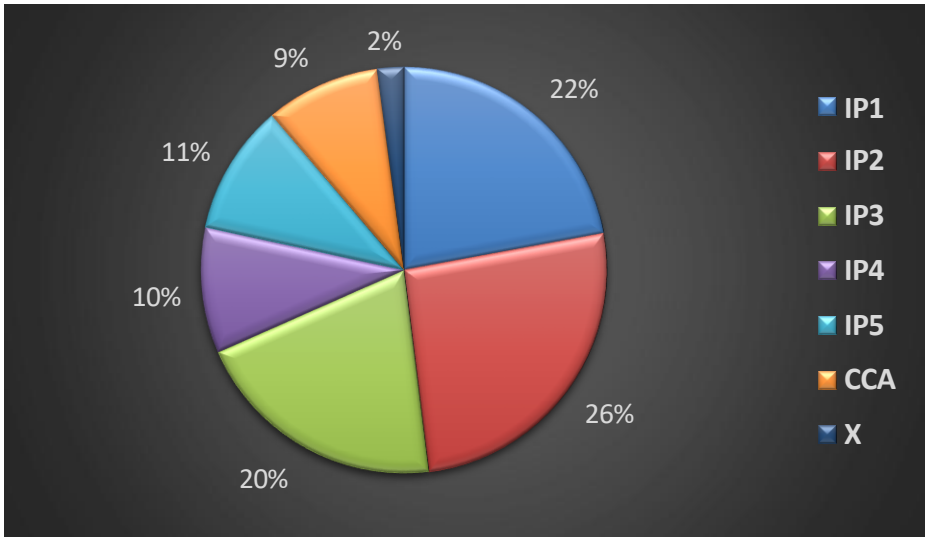


Figure 26-Percentual allocated budget in each IP

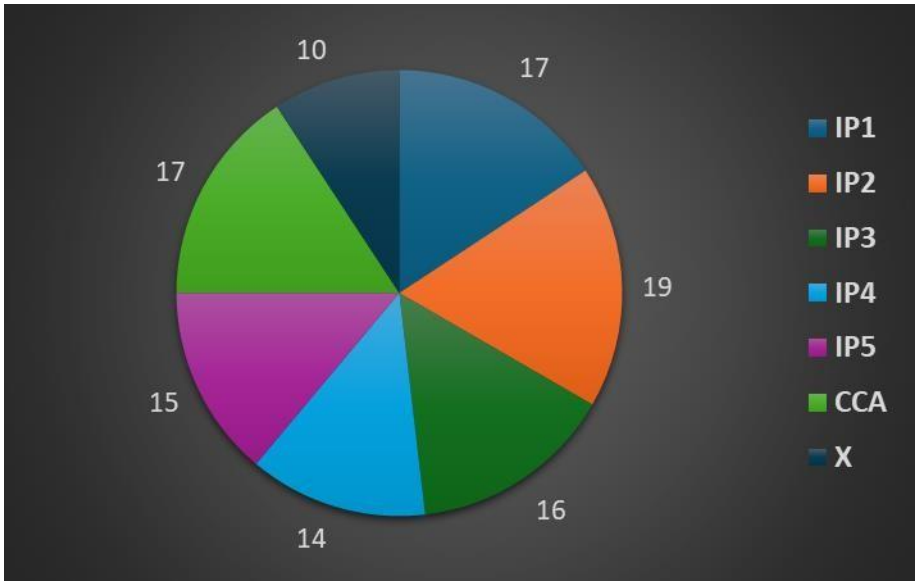


Figure 27-Number of projects in each IP

Figure 28 shows the average budget per project per each starting year and Figure 29 the average budget per partner.

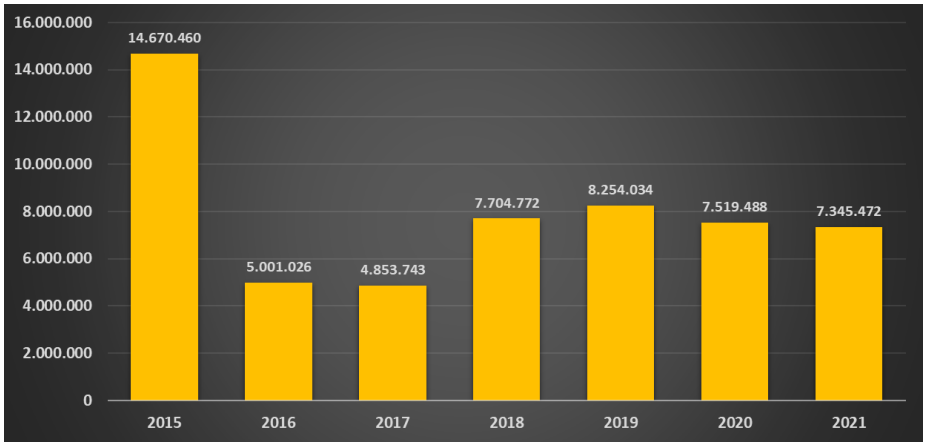


Figure 28-Average budget per project per each starting year

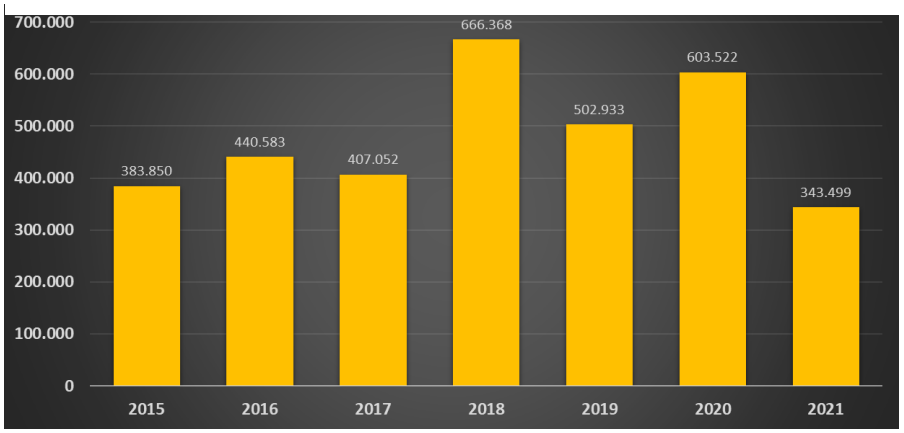


Figure 29-Average budget per partner

Considering all the S2R projects, only 44% of them reported their target Technology Readiness Level (TRL). Among them, Figure 30 represents the distribution of TRL, where emerges that more than 50% targeted TRL4 or TRL5 and only 3% of them targeted TRL9.

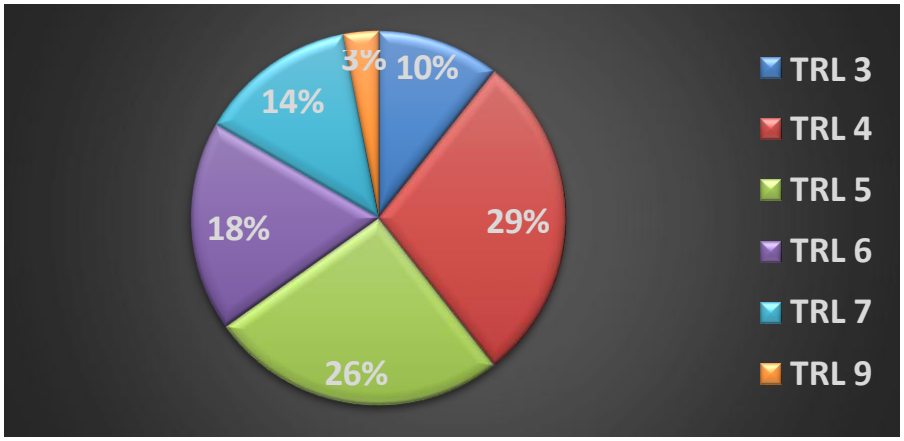


Figure 30-distribution of TRL among projects

Considering the involvement of partners in projects, after the initial year 2015, the number of involved partners remains almost with minimal fluctuations (Figure 31).

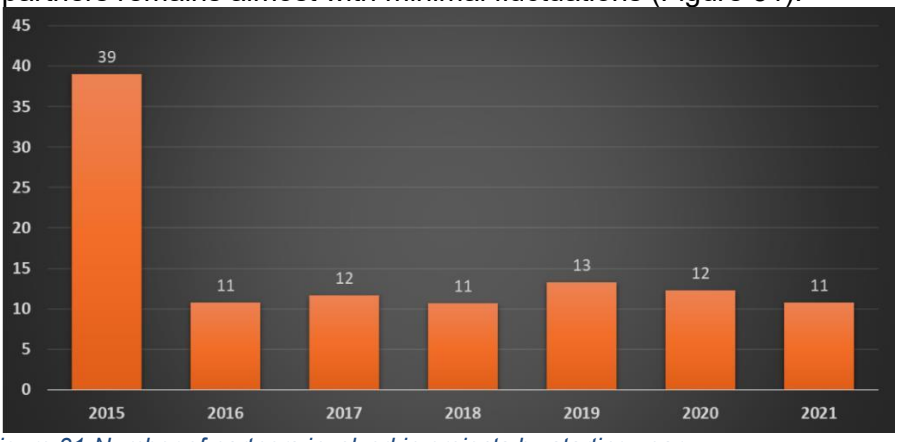


Figure 31-Number of partners involved in projects by starting year

Moreover, figures 32 and 33 represent respectively the average number of months required to complete the projects and the average monthly budget per partner and figures 34 to, 35, 36, 37 and 38 and 39 the number of public Deliverables produced by each project in various IPs and the CCA.

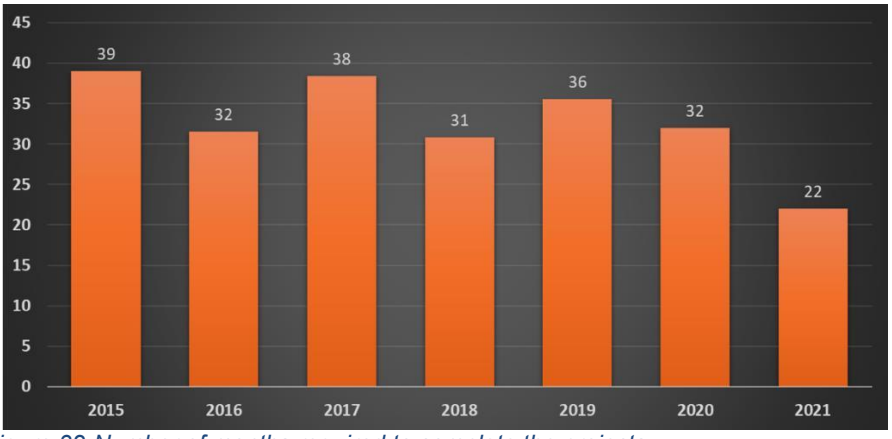


Figure 32-Number of months required to complete the projects

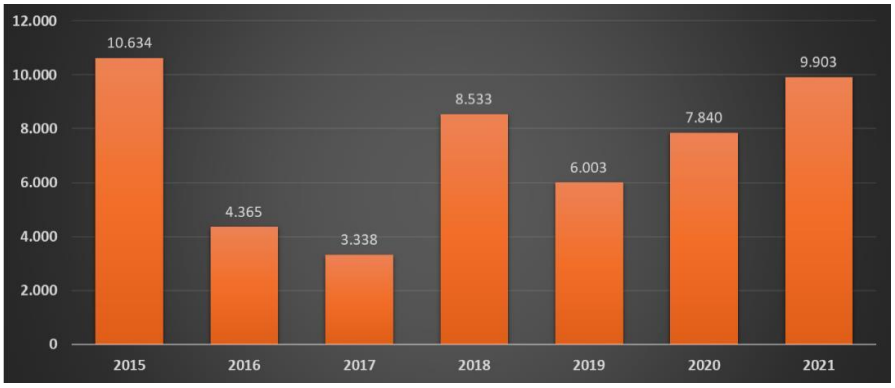


Figure 33-Average monthly budget per partner

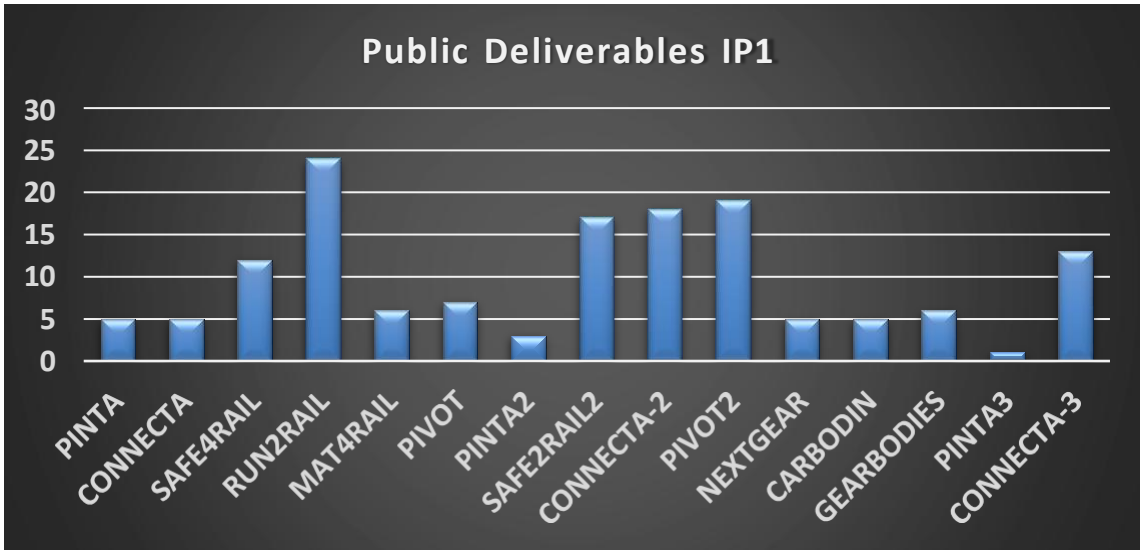


Figure 34-Number of public deliverables produced by projects IP1

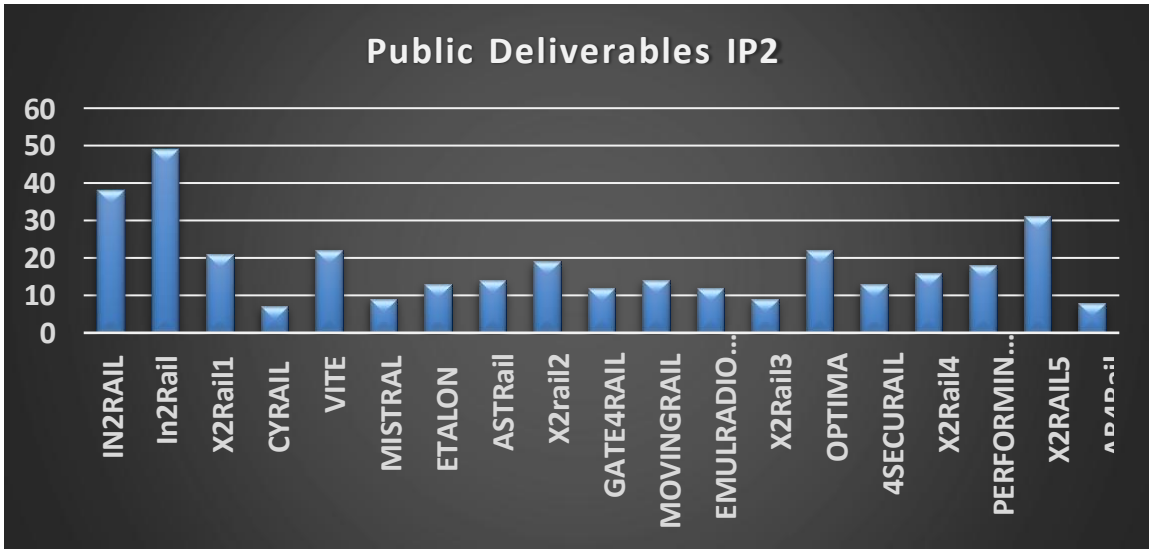


Figure 35-Number of public deliverables produced by projects IP2

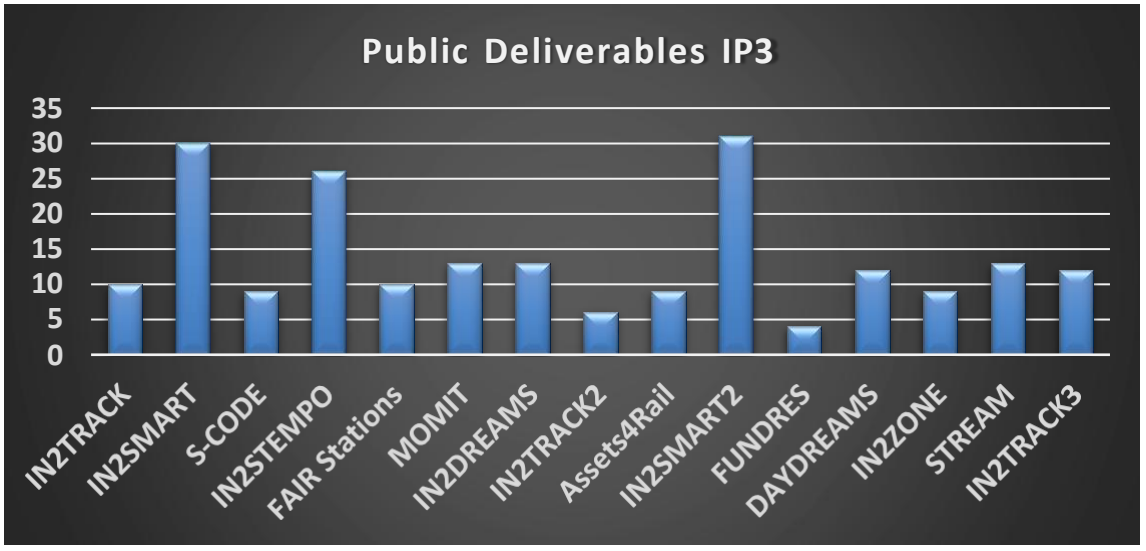


Figure 36-Number of public deliverables produced by projects IP3

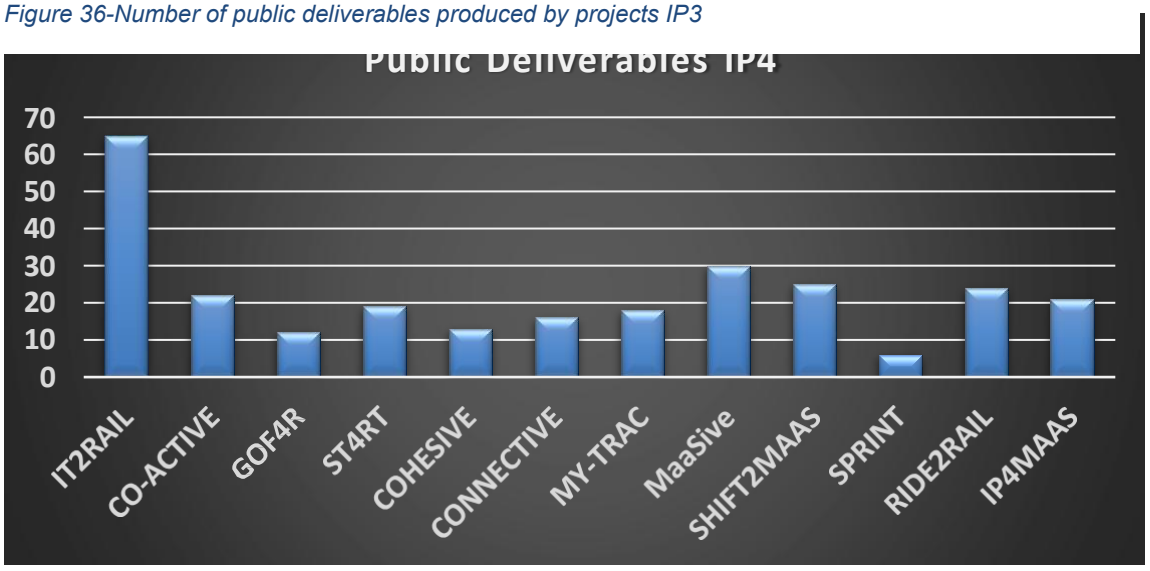


Figure 37-Number of public deliverables produced by projects IP4

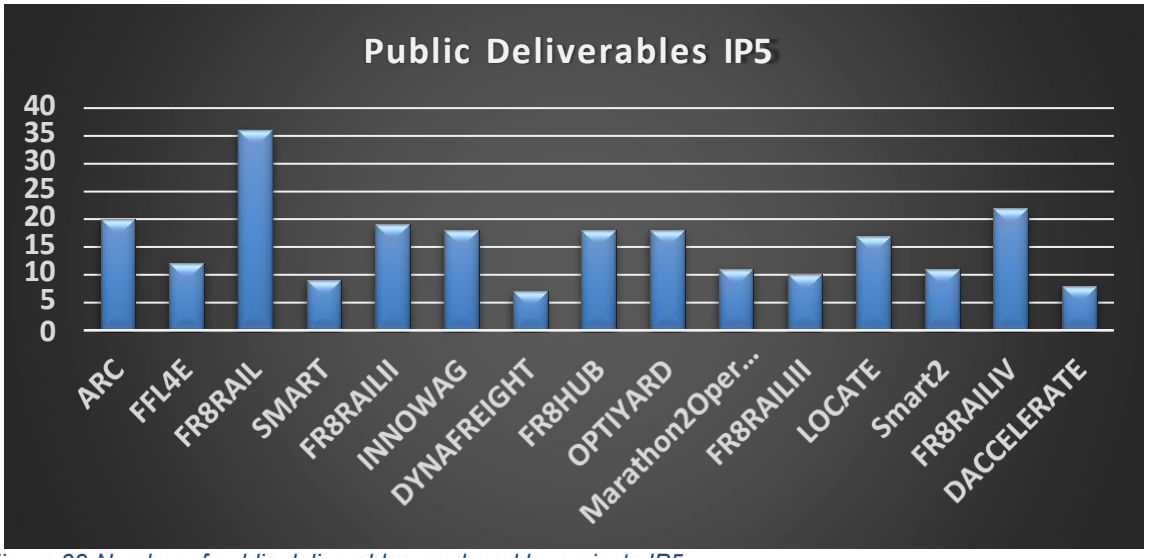


Figure 38-Number of public deliverables produced by projects IP5

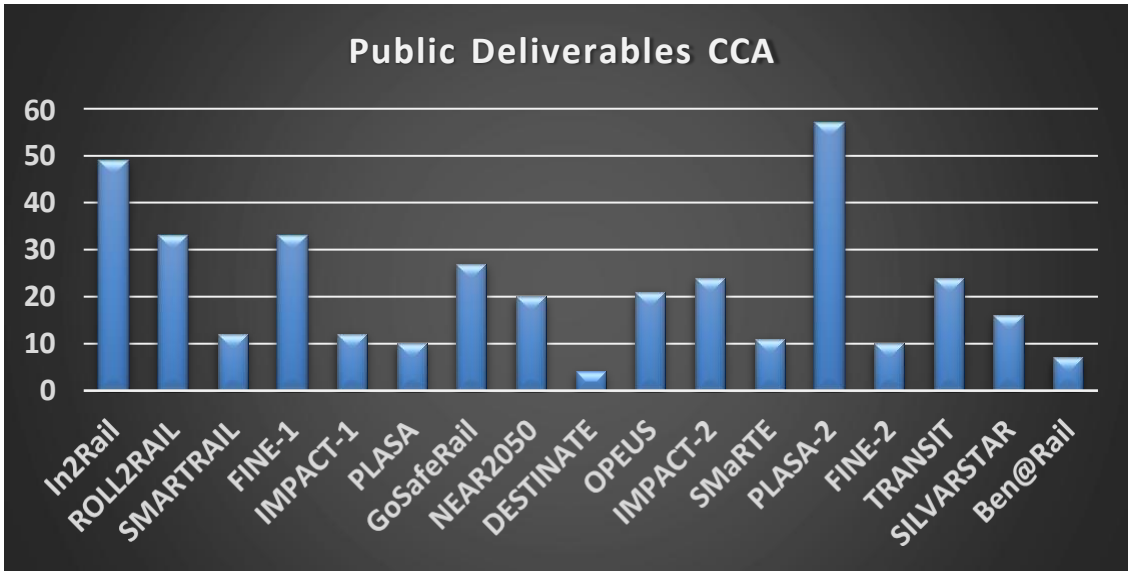


Figure 39-Number of public deliverables produced by projects CCA

Finally, figures 40 to , 41, 42, 43, 44 and 45 represent the number of the publications identified by the digital object identifier (DOI) and figure 46 the number of publications identified by a ISBN only.

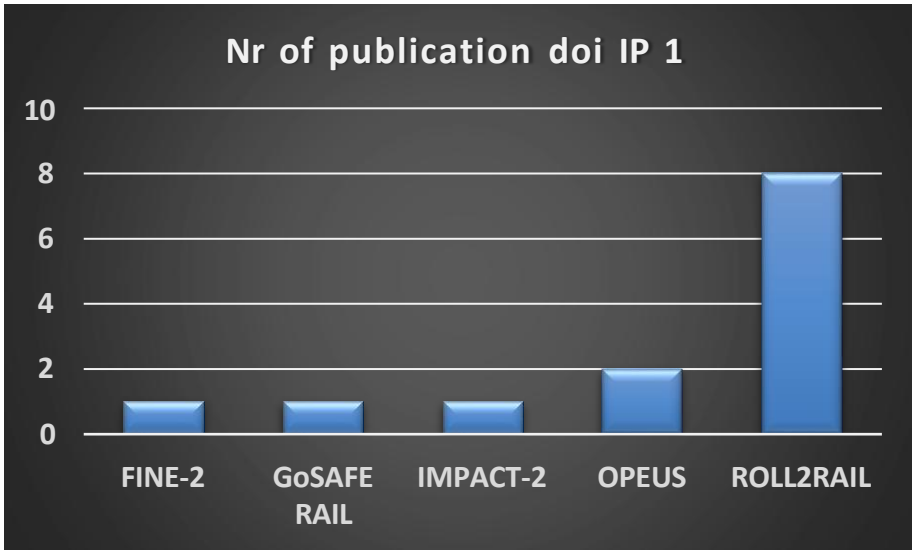


Figure 40-Nr of publication with doi in IP1

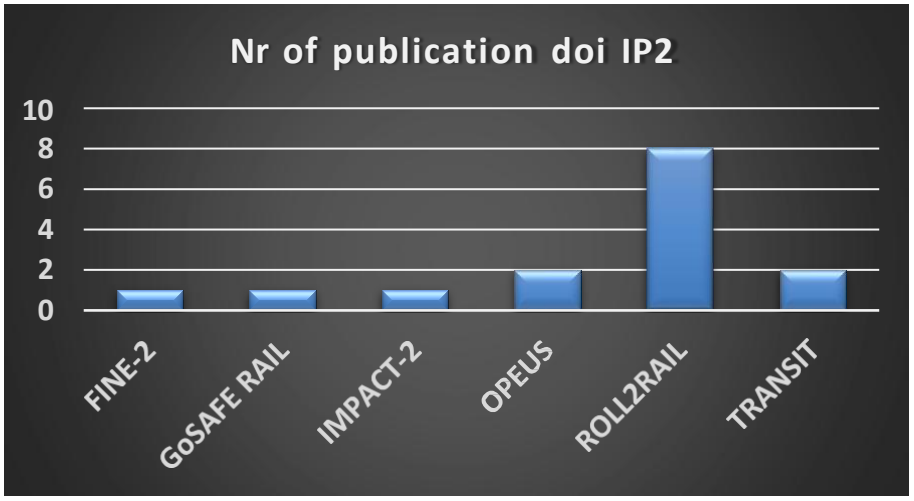


Figure 41-Nr of publication with doi in IP2

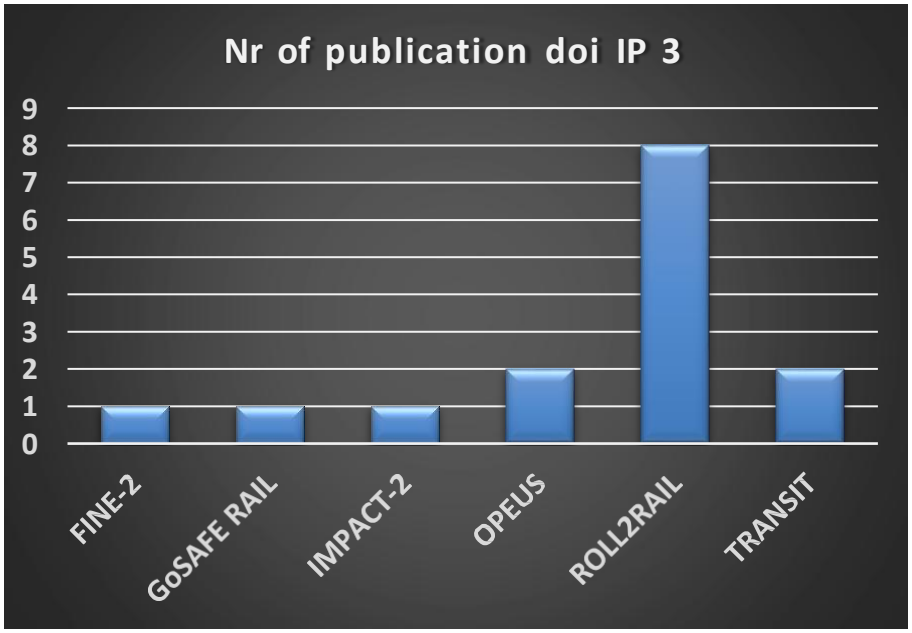


Figure 42-Nr of publication with doi IP3

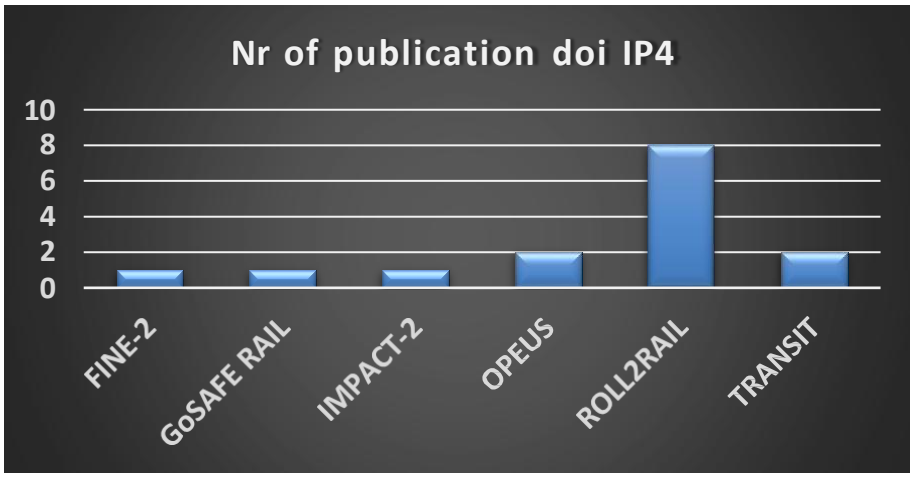
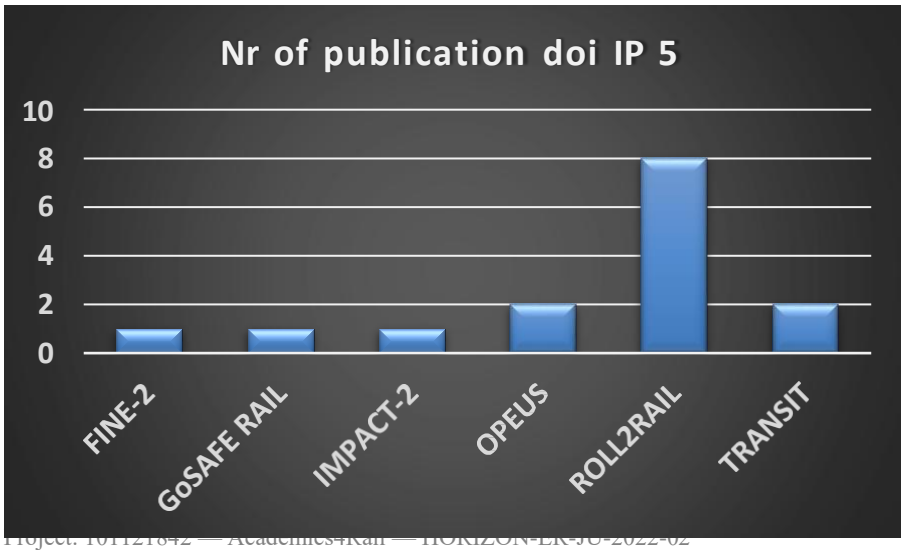


Figure 43-Nr of publication with doi IP4



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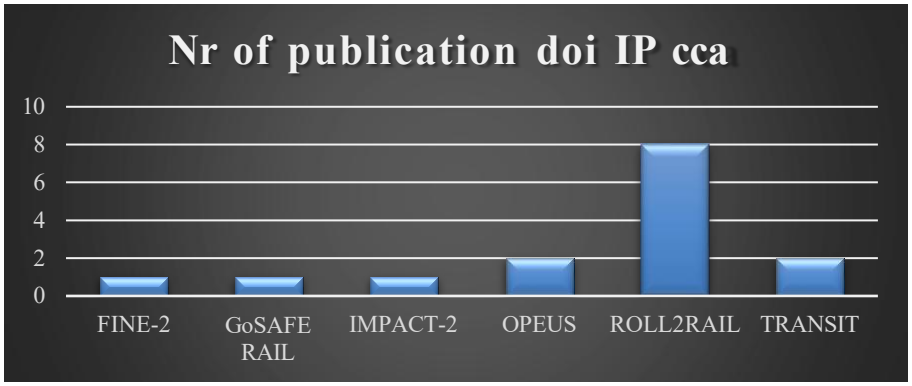

Figure 45-Nr of publication with doi IP in CCA

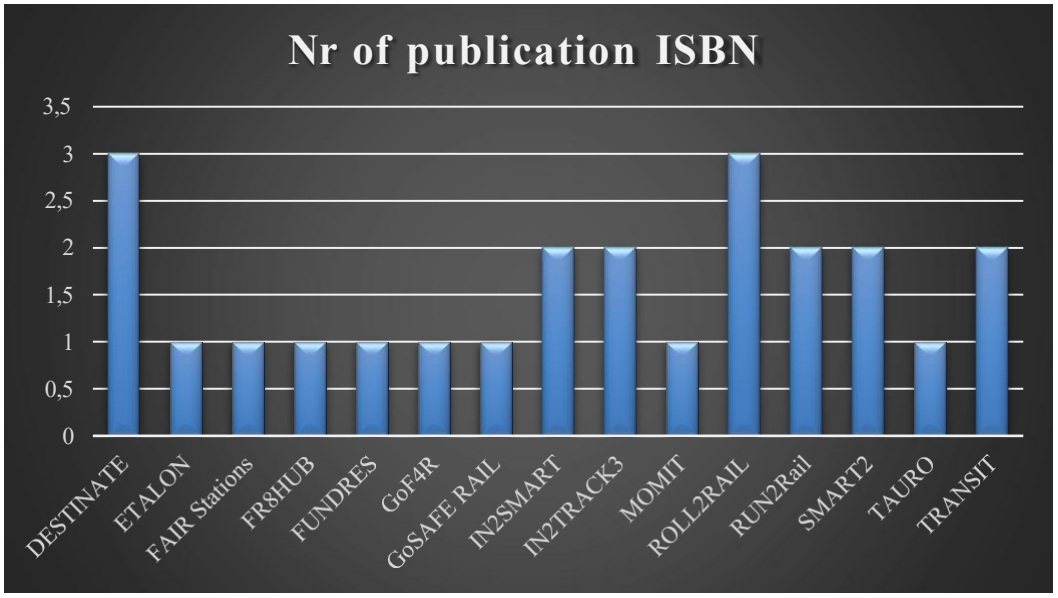

Figure 46-Nr of publication identified by an ISBN only

7.2. The Europe's Rail Joint Undertaking (ERJU)

In 2023, six Flagship Projects (FP) responsible for undertaking the implementation of the Europe's Rail Joint Undertaking Flagship Areas (FA) launched their activities. All projects started the preparatory steps and set up of their working structures and were mostly defined by the end of 2023, with key use cases and requirements for the main technical enablers include in their work-programme. All projects in Flagship Areas (FAs) have also established collaboration among themselves and with the ERJU System Pillar, as summarised in the next paragraphs.

7.2.1. Flagship Area 1: Network management planning and control & mobility management in a multimodal environment

The main objective of Flagship Area 1 (FA1) is to provide solutions to dramatically improve flexibility, efficiency, resilience and adaptation capacity of the European rail network, and enabling the development and operation of a Single European Rail Area (SERA).
FP1-MOTIONAL project is the first project implementing FA1 and aims at contributing to this objective through the development of functional requirements, associated specifications, and operational and technological solutions to enable a future European Traffic Management System that will make rail the backbone of a multimodal transport system for passengers and freight.

The project has a budget of EUR 92.600.000 for the duration of 46 months, from 01/12/2022 to 30/09/2026, and the participation of 87 partners.

7.2.2. Flagship Area 2: Digital & automated up to autonomous Train Operations

The targeted objective of Flagship Area 2 (FA2) is to take the major opportunity offered by digitalization and automation of rail operation and to develop the respective systems. This includes next generation Automatic Train Control (ATC), including Automated Train Operation (ATO) at Grade of Automation 4 (GoA4), building upon radio-based European Rail Traffic Management System (ERTMS) or above, representing the next evolution of the system, incorporating the latest technological advances, and with functionalities enabling full optimization of performance in line with the traffic management improvements developed in FA1. FA2 will aim at delivering scalable automation in train operations with fully unattended train operations including setting a train in motion, driving and stopping the train, opening and closing the doors, remote train control and recovery operations in the event of disruptions.

7.2.3. Flagship Area 3: Intelligent & integrated asset management

The main objective of Flagship Area 3 (FA3) is to provide new innovative technical requirements, methods, solutions and services, including technical requirements and standards for future developments, based on the latest leading-edge technologies to minimise asset life-cycle costs or extend life cycles while meeting the safety and improving the reliability and availability and capacity of the railway system, addressing both infrastructure and rolling stock. IAM4RAIL is the first phase project of the programme that will have a duration of 48 months and 93 participants.

7.2.4. Flagship Area 4: A sustainable and green rail system

The main objective of Flagship Area 4 (FA4) is to provide new innovative products and services based on leading edge technologies to minimize the overall energy consumption and environmental impact of the railway system, to make this transportation mode healthier, more attractive and to provide resiliency against climate change at a reduced total cost of ownership. In the first phase of the programme, FA4 is implemented via the project FP4-Rail4EARTH with a budget of EUR 160.800.000 and the participation of 60 partners.

7.2.5. Flagship Area 5 (FA5): Sustainable competitive digital green rail freight services

The objective of FA5 is to make rail freight more attractive through increased capacity, e.g., with Digital Automatic Coupler (DAC), which is enabling more functionalities in freight to increase network capacity in a smart way for all types of rail freight transport, as well as significantly improved cross border operations and multimodal customer services. Increased capacity is the key factor to enable a shift of transport volumes to rail, reducing substantially the related greenhouse gases emissions. FP5 - TRANS4M-R is the first phase project of the programme that will have a duration of 45 months and 71 participants.

7.2.6. Flagship Area 6 (FA6): Regional rail services / innovative rail services to revitalize capillary lines

The overall objective of Flagship Area 6 (FA6) is to ensure long term viability of regional railways by decreasing the Total Cost of Ownership (TCO), in other words, cost per passenger/ton kilometre both in terms of operational expenditure and capital expenditure, while offering a high quality of service and operational safety. In addition, the aspired results aim to increase customer satisfaction and to make rail an attractive and preferred choice of transport mode. These goals are expected to be achieved through a concept tailored to regional railways that includes digitalization, automation and utilization of mainstream and emerging technologies for signalling and trackside components, rolling stock and customer information. In the first phase of the programme, FA6 is implemented via the project FP6-FutuRe.

7.2.7. Flagship Area 7: Innovation on new approaches for guided transport modes

The objectives of FA7 are to explore non-traditional and emerging flexible and/or high-speed guided

transport systems, as well as to create opportunities for innovators to bring forward ideas for shaping those future systems via a scientific approach into an existing rail system. This shall provide socio-economically efficient and long-term sustainable transport for citizens and businesses throughout Europe. Pods4Rail and MaDe4Rail are the first steps of the programme.

7.2.8. Global Europe's Rail analysis

The ongoing projects funded by the Europe's Rail Joint Undertaking are summarised in Table 15.

Table 15-Research projects in ERJU

Project Title (acronym)	Period		Budget
FP1 - MOTIONAL	01/12/2022	30/09/2026	92.600.000
FP2 - R2DATO	01/12/2022	31/05/2026	160.800.000
FP3 - IAM4RAIL	01/12/2022	30/11/2026	106.900.000
FP4 - RAIL4EARTH	01/12/2022	30/11/2026	95.100.000
FP5 - TRANS4M-R	01/07/2022	31/03/2026	95.100.000
FP6 - FUTURE	01/12/2022	30/11/2026	32.900.000
Pods4Rail	01/09/2023	28/02/2026	2.999.936
MaDe4Rail	01/07/2023	30/06/2024	1.499.328
RAIL4CITIES	01/07/2023	30/06/2025	697.796
InBridge4EU	01/09/2023	31/08/2026	928.115
ESEP4Freight	01/09/2023	31/08/2025	1.299.750
Academics4Rail	01/09/2023	28/02/2027	1.807.238
LEADER 2030	01/07/2023	31/12/2025	700.032
DACcord	01/04/2023	31/03/2026	1.499.829

The average budget per partner provided by the ongoing Europe's Rail project is shown in Figure 47.
The average per month for the same projects is shown in Figure 48.
The targeted Technology Readiness Levels (TRL) are shown in Figure 49.
Figure 50 provides with an overview of the public deliverables that will be issued by each project.

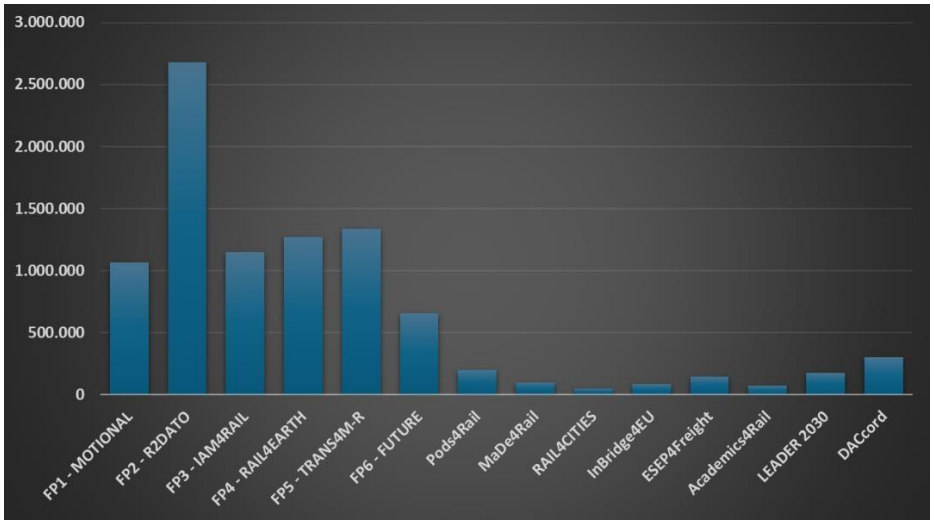

Figure 47-Average budget per partner in ongoing Europe's Rail projects

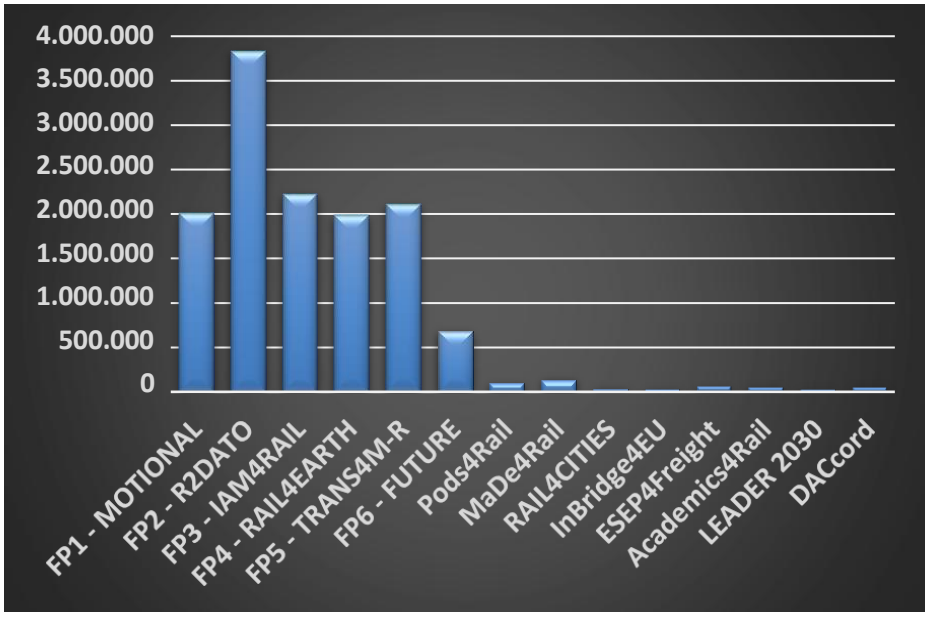

Figure 48-Average budget per month in ongoing Europe's Rail projects

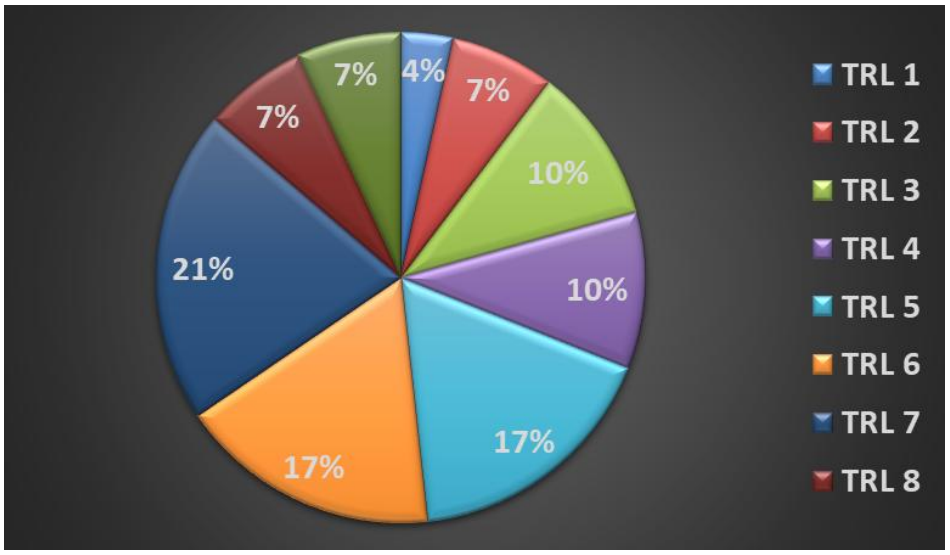

Figure 49-Targeted TRL declared by projects

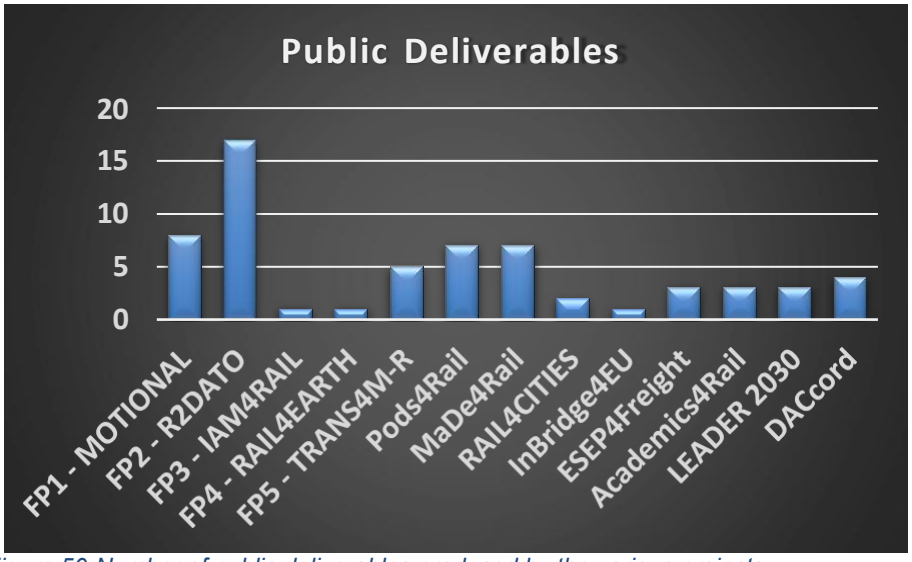

Figure 50-Number of public deliverables produced by the various projects

8 Indicators for measurable progresses

An important aspect to be considered is the introduction of indicators that can measure project progress. Considering the projects analysed and the type of information available, it was possible to formulate the following indicators

Key Performance Indicator	**Definition/ Responding to question**	**Type of data required**	**Data to be provided by**	**Data to be provided in/to**
Participation of RTOs and Universities	Participation of RTOs91 and Universities in PPPs (Art. 187 initiatives)	Number of participations of RTOs to funded projects and % of the total Number of participations of universities to funded projects and % of the total % of budget allocated to RTOs and Universities	H2020 beneficiaries at the grant agreement signature stage	https://data.europa.eu/data/datasets/cordis-eu-research-projects-under-horizon-europe-2021-2027?locale=it
Scale of Impact	Scale of impact of projects: Technology Readiness Level (TRL)	Number of projects addressing TRL between 4-6 and 5-7	Joint Undertaking	https://data.europa.eu/data/datasets/cordis-eu-research-projects-under-horizon-europe-2021-2027?locale=it

Total number of participants	Total number of participants by EU-28 Member State	Nationality of H2020 applicants & beneficiaries (number of countries)	H2020 applicants & beneficiaries at the submission and grant agreement signature stage	https://data.europa.eu/data/datasets/cordis-eu-research-projects-under-horizon-europe-2021-2027?locale=it
Publications in peer reviewed high impact journals in JU areas	Percentage of papers published in the top 10% impact ranked journals by subject category	Publications from relevant funded projects (DOI: Digital Object Identifiers). Journal impact benchmark (ranking) data to be collected by commercially available bibliometric databases.	H2020 beneficiaries through project reporting; Responsible Directorate / Service (via access to appropriate bibliometric databases)	https://data.europa.eu/data/datasets/cordis-eu-research-projects-under-horizon-europe-2021-2027?locale=it

9 Synthesis of steps 1 and 2 to build the architecture of a scientific observatory

The steps described in the previous sections represent the processes that will initialize and continuously feed the scientific observatory to be realized by the A4R consortium.
In this context, it is worth mentioning that the objective of the Observatory is to provide a continuous monitoring and evaluation of research activities in the railway sector in order to provide guidelines, trend analysis and indications for research and gap filling.
Therefore, it is possible to identify the following links between the activities carried out in the first 12 months and those described above and the objective of the Observatory.

9.1. Results of steps 1 and 2

The activities of Step 1 consisted of reviewing the Shift2Rail MAWP, calls for proposals, project deliverables, interim and final evaluation reports, with reference to achievements that can lead to quantifiable advances in knowledge and possible improvements in the performance of rail-based transportation systems, both now, through successful implementation actions, and in the future, through publications and deliverables relevant to the scientific community.
The result of this activity is a database of achievements to date, together with an analysis of the benefits and impacts on the rail industry. Such an analysis was possible because many of the projects have been completed and the use case descriptions as well as the final demonstrators are available.
Regarding the second step, the relevant activities consisted of the analysis of the technical documents generated during the transition from Shift2Rail to ERJU and up to the ERJU MAWP, with a focus on the establishment of a rail systems knowledge base, starting with the IP and pillars in Shift2Rail and the ERJU Flagship Areas.
Analogous to step 1, this analysis provided a database of the research performed and, more specifically, of what has "evolved" from Shift2Rail to ERJU (and how), in order to identify the research topics that have been explored in Shift2Rail and migrated (if still worthy of investigation) and abandoned, also considering the potential topic transformation determined by the basic and applied research performed in the wider fields of science and technology. Note that such a database also

makes it possible to determine the gaps to be filled, for example by identifying research results that have been promoted from low to higher TRLs, demonstrating their relevance, but that are not yet ready for the highest TRL.
In summary, the activities carried out at the time of the given deliverable represent the initial database of the architecture, which, in the context of a living scientific observatory, will need to be continuously fed and updated.

9.2. Assessing tool for the scientific observatory and role of steps 1 and 2 in the architecture

The database described above collects research activities that are being carried out at different TRLs and/or that have demonstrated their effectiveness and impact on rail with varying degrees of success. Therefore, in order for the Scientific Observatory to achieve its goal of transferring the latest advances in science and technology to the railway industry, it is necessary to develop evaluation tools aimed at assessing the effectiveness and impact of research in the railway sector. Such an activity, which will be developed in the next phases, will be directly integrated in the Observatory architecture, which will be developed as schematically represented in Figure 51.

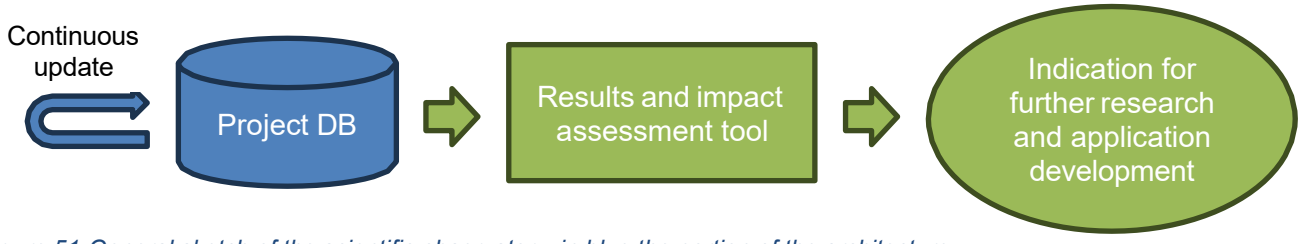

Figure 51-General sketch of the scientific observatory; in blue the portion of the architecture developed in the steps 1 and 2.

10 Draft Architecture of a Scientific Observatory for ERJU

The proposed scientific observatory will serve as a dynamic and evolving platform that aligns with the latest advancements in science and technology, specifically focusing on the rail industry. The observatory aims to provide a structured roadmap that transcends the current state of the art, guiding the European rail sector towards its ultimate goals. A special emphasis will be placed on monitoring and evaluating projects that incorporate Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT) and big data analytics, including technologies for autonomous driving and predictive maintenance.

10.1 Objectives

1. Continuous Update Mechanism: Implement a framework for continuously integrating the latest scientific and technological developments into the observatory.
2. Roadmap Development: Establish a clear roadmap to trace and plan steps beyond the current state of the art.
3. Focus on AI and Big Data Projects: Prioritize monitoring initiatives and projects that leverage AI, ML, IoT and big data analytics.
4. Collaboration and Integration: Facilitate collaboration across various ongoing and previous projects such as RAILS, SMART, IN2RAIL, ATTRAkTIVE, IN2SMART, TAURO, etc.

10.2 Components

10.2.1 Data Collection and Repository Layer

- Data Sources: Collect data from rail projects (ERJU) and CORDIS and TRIMIS.
- Data Repository: Establish a centralized repository for storing and managing collected data.

10.2.2 Project Monitoring and Evaluation Module

- Project Database: Maintain a comprehensive database of past, ongoing, and future projects related to AI, ML, IoT and big data analytics.
- Evaluation Framework: Develop criteria and methodologies for evaluating the progress and impact of these projects.

10.2.3 Knowledge Integration and Analysis Platform

- Knowledge Base: Create a structured knowledge base that integrates findings from various projects and research initiatives.
- Analysis Tools: Provide tools for analysing trends, identifying gaps, and generating insights based on the collected data.

10.3 Implementation Plan

Phase 1: Setup and Initial Integration

- Establish the infrastructure for data collection and repository,
- Begin integrating existing datasets and project outputs.

Phase 2: Development of Monitoring and Evaluation Tools

- The development of the initial database is part of the work described in the present Deliverable and has been eliminated from the implementation plan (phase 2),
- Start evaluating selected projects to assess the framework's effectiveness.

Evaluation tools should be follow-up of the Observatory, in the framework of the implementation plan (phase 2).

Phase 3: Launch of Knowledge Integration and Analysis Platform

- Community and Collaboration Portal for knowledge sharing and collaboration.

11 Conclusion

In light of the Shift2Rail and Europe's Rail Joint Undertaking (ERJU) efforts, the "Academics4Rail" project is a major step in closing the gap between academic research and the changing needs of the European rail industry. This deliverable has built a database and analytical framework that would form the core of the proposed scientific observatory through an analysis and synthesis of previous and continuing research initiatives.

The following summarized conclusions can be drawn:

1. **Shift2Rail Achievements:**
   - Shift2Rail, a public-private partnership, has made significant strides in advancing rail technologies. Its focus on improving interoperability, traffic management, cost-efficiency, and sustainability has laid a solid foundation for future innovations.
   - The program's structure into Innovation Programs (IPs) targeting specific areas, such as cost-efficient trains, advanced traffic management, high-capacity infrastructure, and sustainable rail freight, has yielded positive outcomes. Each IP has contributed to improving both technical performance and environmental impacts.
   - There is strong emphasis on digitalization, automation, and cross-cutting activities like human factors and noise management. These areas have proven critical in enhancing the railway system's overall performance and integration across Europe.
   - The inclusion of Small and Medium-sized Enterprises (SMEs) and collaboration with research centers and universities have expanded the innovation landscape within the European rail sector enabling a substantial output in research publications that enhanced the relevance of European funding for scientific research.
2. **Shift2Rail and ERJU Transition:**
   - As Shift2Rail transitioned into the Europe's Rail Joint Undertaking (ERJU), there was a continuation of key priorities, with added focus on new digital technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Big Data for predictive maintenance and autonomous driving.
   - ERJU Flagship Areas have been established, targeting crucial objectives like automated train operations, sustainable and green systems, and intelligent asset management. These are well-aligned with the goals set in Shift2Rail but reflect an evolution in focus toward future technologies and sustainability.
3. **Funding and Project Management:**
   - Funding allocation across different IPs and Flagship Areas was generally well-structured, with attention to both infrastructure and operational innovations. However, there were fluctuations in budget and partner participation year by year, suggesting some instability in long-term funding consistency.
   - The creation of cross-cutting activities in both programs helped streamline research across various innovation areas. However, more could be done to integrate lessons learned from different IPs and make better use of interdisciplinary innovations.
4. **Gaps and Areas for Improvement:**
   - While there were many advances, certain areas, such as the technology readiness level (TRL) of research outputs, need improvement. A majority of projects focused on

TRL 4-5, with fewer reaching TRL 9, indicating that there is still a gap between research and market-ready technologies.

- There is a need for better long-term planning to ensure continuous progress toward automation, digitization, and sustainable systems. Some projects did not fully address long-term impacts on operational performance and user experience, which could be crucial in fulfilling EU rail's full potential. While the achievements of Shift2Rail and the transition into Europe's Rail Joint Undertaking (ERJU) demonstrate substantial progress toward innovation in rail transport — particularly in automation, digitization, and sustainability — the analysis reveals an opportunity to further strengthen long-term planning efforts. A review of project outcomes shows that although many initiatives have successfully targeted mid-level technology readiness (TRL 4–5), relatively few have matured to higher TRL levels (TRL 8–9), which are critical for deployment and real-world operational impact. Additionally, budget allocations and partner participation patterns over the years indicate some variability, suggesting room for improvement in ensuring continuity and strategic coherence.
  Furthermore, while there has been commendable engagement with research institutions and industry, expanding collaboration with Small and Medium-sized Enterprises (SMEs) and academia — particularly in disruptive innovation areas such as Artificial Intelligence (AI), cybersecurity, and smart mobility — would further strengthen the innovation ecosystem. Broader involvement of these actors not only enriches the research landscape but also ensures a dynamic pipeline of ideas and fosters faster transfer of technology into market-ready solutions.
  Strengthening the focus on long-term impacts, both in technological maturation and stakeholder engagement, would help maximize the return on investments and ensure that the European rail system fulfills its full potential as a global leader in innovation and sustainability. This recommendation is not a critique but a natural extension of the excellent progress already made, ensuring that future initiatives build steadily on the strong foundations established so far.

Recommendations for Future Improvement

1. Focus on Higher TRL and Commercialization:
   - A clear focus should be put on moving projects from mid-TRL (4-6) to higher TRL (7-9). This would require not only technical refinement but also greater attention to the commercial aspects of innovation, ensuring that technologies are market-ready and can be adopted by the industry.
2. Expand Digitalization and Automation Research:
   - Emphasize further research into autonomous train operations and intelligent systems. AI and IoT-based solutions, especially in predictive maintenance and traffic management, should be prioritized to fully automate operations and improve efficiency.
3. Enhance Collaboration with SMEs and Academia:
   - Increasing the involvement of SMEs and research institutions, especially in disruptive innovation areas like AI, cybersecurity, and smart transportation, will help to maintain a competitive edge in rail technology not only at scientific level but also and most importantly at industrial and human capital level.
4. Strengthen Multimodal and Green Transportation:
   - Expanding efforts on developing a sustainable, multimodal European rail system is essential. More emphasis should be placed on environmental technologies, such as energy-efficient designs and zero-emission solutions, to meet the EU's Green Deal targets.
5. Improved Project Continuity and Funding:
   - To ensure that long-term research goals are met, the EU should maintain consistent funding and project management structures. This includes avoiding large fluctuations in partner participation and project timelines.

6. Development of the Scientific Observatory:
    - The proposed scientific observatory for the ERJU is a promising step forward. This tool should be further developed and used to track research progress, identify gaps, and ensure that emerging technologies are quickly integrated into the rail sector.

In summary, while the EU's rail research programs, particularly Shift2Rail and ERJU, have made significant advances, there is room for improvement in commercialization, digitalization, sustainability, and long-term project continuity. The establishment of a scientific observatory and continued collaboration between industry, academia, and SMEs will be key to ensuring that European rail systems remain at the forefront of global innovation.

The observatory's architecture aims to keep research efforts in line with the overall objectives of the ERJU by regularly monitoring, assessing, and incorporating the most recent scientific and technological developments into the rail industry.

As time goes on, the establishment of the scientific observatory will not only offer a well-organized research agenda but will also promote increased cooperation between European institutions, business, and academia. By doing this, the European rail network will be able to fulfill the demands of a transportation landscape that is evolving quickly and stay at the forefront of global innovation. The observatory's ongoing development and improvement, along with the addition of assessment instruments, will establish it as a crucial asset for expanding the technological prowess and sustainability of the European rail industry. In the end, this project will help make the Single European Rail Area (SERA) a reality, resulting in a future transportation network that is more effective, dependable, and environmentally friendly.