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DELIVERABLE REPORT

WP2 - MGT2 - Pilot scheme for the management of a distributed research infrastructure offering harmonised, interoperable and integrated services

D2.9
Schemes for a sustainable technical and scientific long-term management

This initiative has received funding from the EU's H2020 framework program for research and innovation under grant agreement n. 101007417, NFFA-Europe Pilot Project

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1. Introduction

The Integrated Distributed Research Infrastructure for Nanoscience (IDRIN) has been conceived as a coordinated and interoperable operational model for a distributed research infrastructure bringing together the facilities and services offered by the NEP consortium under a common coordinated framework. The NFFA-Europe IDRIN encompasses a broad ensemble of access providers, including both beneficiaries and Third Parties providing access against Payment (TPaP), whose complementary scientific and technological capabilities collectively form a single and unique European Research Infrastructure (RI) for the science of matter and advanced materials at the nanoscale, with upscale to micro analysis and technology.

While maintaining the distributed nature of its constituent facilities, the IDRIN is designed to operate as a single integrated RI. Its operational model combines geographically distributed installations with central coordination mechanisms and local operational nodes, enabling harmonised access procedures, coordinated service delivery, and effective interoperability among providers. Through this approach, users can access via a Single Entry Point (SEP) a broad portfolio of techniques, instruments and expertise through a common framework, independently of the location of the resources required to perform their research.

The coordinated operation of IDRIN relies on several dedicated components, each addressing a specific aspect of the infrastructure management. Scientific quality is ensured through the Access Review Panel (ARP), an independent external peer-review body responsible for evaluating the scientific merit of user proposals. Technical coordination is ensured by the Technical Liaison Network (TLNet), a distributed network composed of a central coordinating node and local nodes at provider sites, assessing technical feasibility, supporting users, and coordinating the implementation of optimised work plans across co-located and distributed facilities.

The user-oriented dimension of the infrastructure is supported by the User Office Network (UONet) that coordinates the activities of local User Offices, aiming at the provision of harmonised administrative and logistical services throughout the access lifecycle. Through common procedures

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and shared service standards, UONet supports users in matters such as travel and subsistence reimbursement, logistics, legal and insurance aspects, while contributing to the integration of administrative information across the infrastructure.

A further fundamental component of IDRIN is the data management framework, which supports the implementation of FAIR data principles and promotes advanced data stewardship practices across all infrastructure activities. The data management platform provides an integrated environment linking scientific datasets, metadata and access-related information, enabling the production, storage and exploitation of FAIR research data while supporting monitoring, reporting and future socio-economic analyses of the infrastructure usage.

Together, these coordination components provide the scientific, technical, operational and data-management foundations required to operate the IDRIN as a coherent distributed infrastructure. To support the development of sustainable schemes for the long-term technical and scientific management of the IDRIN, the coordinators of the main operational components were invited to assess the strengths and weaknesses of the current operational model and explain their view on the needs for its further evolution. The analysis presented in this deliverable is based on their contributions and on the common themes emerging across the different coordination areas.

2. Strengths and weaknesses of the current IDRIN

The assessment of the current IDRIN operational model revealed several strengths that support the effective operation of the RI, as well as weaknesses and challenges that may affect its long-term sustainability. The following sections summarize the main findings for each of the key coordination components.

2.1 Strengths

2.1.1 Technical Liaison Network (TLNet)

The Technical Liaison Network (TLNet) represents the technical backbone of the NFFA-Europe IDRIN, enabling the coordinated management of a highly distributed RI characterized by multiple providers offering overlapping and complementary capabilities. Through its distributed structure of central and local nodes, the TLNet has established an effective mechanism for technical feasibility assessment and optimization of complex multi-technique and multi-site access projects, facilitated by a fully on-line management platform. The model allows the identification of the most suitable instruments and expertise for each user proposal, ensuring that access pathways are tailored to specific scientific needs rather than being constrained by the initially selected provider.

A further strength of the TLNet is its ability to facilitate continuous interaction among instrument scientists, providers and users. This collaborative approach promotes the optimization of work plans and supports multidisciplinary solutions that may not emerge within a traditional single-facility access model. The combination of distributed expertise and dedicated monitoring tools has therefore contributed significantly to the integration and interoperability of the infrastructure while making advanced access opportunities available also to less experienced users.

2.1.2 User Office Network (UONet)

The User Office Network (UONet) provides a coordinated administrative and logistical support framework for users throughout the access lifecycle. A major strength of the network is the adoption of standardized Welcome Packs and common operational guidelines, which ensure a consistent level

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of information and support across several distributed access sites. These resources facilitate the user interaction with the RI by providing clear information on administrative procedures, travel and subsistence rules, local logistics and access requirements.

UONet also benefits from the integration of dedicated functionalities within the SEP, including automated notifications, access monitoring tools and dynamic management of access documentation. These tools enhance traceability, transparency and coordination among User Office nodes. In addition, the hub-based reimbursement model – i.e. the responsible beneficiary manages reimbursements on behalf of affiliated Third Parties - has contributed to streamlining financial management processes for Third Parties and has enabled a more structured approach to reimbursement management within the distributed infrastructure.

2.1.3 Data Management and Data Services

The overarching data management framework combines strategic planning, technical implementation and user-oriented service development within a coherent FAIR-oriented vision. A major strength lies in the existence of a structured roadmap linking FAIR objectives, infrastructure requirements, responsibilities and implementation milestones, allowing a progressive transition from early planning to operational services.

Another significant asset is the diversity of the service portfolio developed within the infrastructure. An overarching area does not focus on single technical solutions, but develops complementary capabilities covering data stewardship, metadata management, image analysis, modelling and machine-learning-based services, reflecting the real variety of user needs across facilities and disciplines.

The data management model also successfully combines centralized coordination with distributed expertise contributed by multiple partners: Different partners provide specialized knowledge and domain-specific tools, while the overall work-plan remains aligned with the project goals.

Overall, an overarching data management and data services area is fundamental to successfully combine policy, infrastructure and concrete services into an operational pathway that is realistic, progressive, potentially upscalable, and already capable of supporting a broad set of FAIR data activities.

2.1.4 Access Review Panel (ARP)

The Access Review Panel (ARP) has developed a robust "high-quality" evaluation procedure that combines scientific rigor with operational flexibility. A key strength of the current model is the assignment of each proposal to two reviewers who jointly prepare a single evaluation report before the proposal is discussed by the full panel. This approach promotes consensus-building at an early stage of the evaluation process, improves the consistency of assessments across different scientific domains, and reduces dependence on the presence of individual reviewers during plenary meetings. As a result, the ARP can maintain continuity and efficiency in its evaluation activities while preserving the quality and transparency of the review process.

A further strength is the close interaction between the ARP and the Technical Liaison Network (TLNet) through the Scientific Officer. This interface enables a rapid and effective exchange of information between the scientific and technical evaluation processes, ensuring that scientific excellence and technical feasibility are considered in a coordinated manner. At the same time, the arrangement allows the ARP to remain fully independent in its scientific assessments while being continuously informed about infrastructure capabilities, operational constraints and strategic

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priorities. This contributes to a balanced evaluation process that aligns scientific quality with the effective use and development of the infrastructure.

2.2 Weaknesses

2.2.1 Technical Liaison Network (TLNet)

The main limitations of the current TLNet model derive from the complexity inherent to the coordination of many distributed facilities, instruments and technical experts. The technical feasibility assessment and optimization process require the active participation of numerous instrument scientists, resulting in a substantial commitment of human resources even when access is ultimately assigned to only one provider among several potential candidates.

This intensive effort may negatively affect long-term motivation, particularly when technical assessments become repetitive or when the scientific involvement of facility staff is perceived as limited with respect to the effort invested. Furthermore, the experience gained through the technical evaluation of many research projects and through the peer-review with the colleagues of the distribute infrastructure is a subjective aspect, which depends greatly on the individual approach of the several scientists. The outcome of the evaluation is therefore stored in a patchy manner and struggles to become an objective common value of the infrastructure itself; this also weakens a sense of being part of a valuable common effort for the benefit of the international scientific community.

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2.2.2 User Office Network (UONet)

The main weaknesses identified within UONet stem from the heterogeneity of the legal, administrative and organisational environments in which the different providers operate. Significant differences in the flexibility and capacity of local User Offices create uneven levels of administrative support and may contribute to role ambiguities between administrative and scientific personnel.

The distributed nature of the infrastructure also complicates the harmonisation of procedures, particularly in relation to travel and subsistence reimbursement, financial accountability and management of multi-site access. Existing reimbursement mechanisms may generate administrative burden, delays and reduced transparency for users. In addition, the limited interoperability among administrative systems and the incomplete implementation of some services at network level still limit real-time monitoring and fully integrated management across the infrastructure.

More generally, several UONet activities remain strongly influenced by the constraints of project-based funding mechanisms, which may limit the degree of institutionalisation and long-term stability of the current model.

2.2.3 Data Management

The implementation of FAIR principles across the wide variety of techniques and scientific domains supported by the IDRIN is demanding, especially for the definition of community-agreed standard for metadata. As dedicated commitment is required for each scientific technique, FAIRification activities are resource-intensive.

The sustainability of the current model also depends heavily on the presence of a sufficient number of specialised contributors responsible for service development, maintenance and support. In addition, new developments are necessary to further limit and possibly avoid manual intervention by users or instrument scientists, particularly around metadata completion, format conversion and service-specific preparation steps. Finally, although monitoring mechanisms are available, feedback

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collection and performance assessment processes need to be further consolidated to provide a more systematic basis for service prioritisation and service lifecycle management.

2.2.4 Access Review Panel (ARP)

The increasing number of proposals submitted to the infrastructure has placed a growing workload on individual reviewers and on the overall evaluation process. In particular, the ARP has experienced difficulties in covering the expanding volume of proposals in in specific domains, where the expertise available within the panel has not always been sufficient to address the demand. This has required the involvement of external reviewers, increasing the organizational effort needed to ensure an appropriate scientific assessment.

A further challenge is represented by the periodicity of the calls. The current schedule, with calls issued every three months, results in a demanding evaluation cycle and can make it difficult to identify suitable time slots for plenary ARP meetings that accommodate the availability of reviewers. As proposal numbers increase, maintaining an efficient and timely evaluation process becomes progressively more challenging.

Finally, the current evaluation workflow is only partially integrated into the Single Entry Point (SEP). The absence of reviewer reports and related scientific evaluation records within the central platform limits the overall visibility of proposal histories and assessment outcomes. This makes proposal management less efficient and prevents reviewers and coordinators from having an immediate and comprehensive overview of the scientific status of proposals, including previous submissions from the same users and their evaluation history.

This model, albeit successful in ensuring quality and relevance of the granted user's access, is heavily relying on voluntary work by high-reputation scientists, which has been successfully managed through the NEP years, but has also evidenced a perspective expert-sustainability issue to be addressed in the future.

2.3 Implications for the scientific and technical quality of access

The strengths and weaknesses identified across the different coordination components have a direct impact on the scientific and technical quality of access provided by the NFFA-Europe IDRIN. Overall, the current model has demonstrated a strong capability to support high-quality, multi-method and interdisciplinary research by combining scientific excellence, technical expertise, user support services and advanced data management within a single distributed RI. At the same time, the increasing complexity associated with the operation of such a distributed system highlights several challenges that may affect its long-term efficiency and scalability.

One of the main strengths of the current model is its ability to provide access workflows tailored to the scientific objectives of users rather than to the technical offer of individual facilities. The integrated approach offered by the IDRIN enables multi-technique and multi-site research projects that exploit the full capabilities of the infrastructure ensuring optimal implementation and allowing for comprehensive scientific investigations that would not be possible within a single facility. A seamless combination of access to top-level laboratories throughout Europe allows supporting a broad range of scientific disciplines, techniques and application domains, attracting a highly diverse user community and promoting cross-disciplinary research. The possibility of combining synthesis, nanofabrication, characterization, theory, modelling and advanced data services within a common framework further increases the scientific value of the access provided and contributes to the generation of innovative research outcomes.

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The current model also contributes positively to technical quality through the extensive involvement of facility staff and technical experts. The feasibility assessment process and the continuous interaction among providers foster the identification of the most appropriate instrumentation, methodologies and expertise for each project. This often results in significant optimization of work plans before access is granted, improving the likelihood of successful scientific outcomes and making advanced infrastructures accessible also to less experienced users.

In parallel, the availability of user-support services and data-management frameworks improves the overall effectiveness of access. Monitoring tools, FAIR-oriented data services and shared operational platforms help users navigate the complexity of a distributed infrastructure and facilitate the production of high-quality, reusable scientific outputs. The integration of data stewardship activities with access services contributes to reproducibility, discoverability and long-term exploitation of research results.

However, several weaknesses identified in the current model also have implications for scientific and technical quality. The increasing workload associated with proposal evaluation, technical feasibility assessment, operational support and the coordination of a large number of distributed providers places significant pressure on reviewers, instrument scientists and support personnel. As proposal numbers continue to grow, maintaining the same level of detailed scientific and technical scrutiny may become progressively more challenging. This is particularly evident in scientific domains where the available expertise is limited. A reduced level of commitment of the RI personnel involved, both on technical and administrative aspects, could ultimately affect the effectiveness of access planning, the quality of scientific support provided to users and the overall scientific value of the projects enabled by the infrastructure.

From a data-management perspective, inequalities in service level and the effort required to implement FAIR practices across diverse techniques may lead to uneven levels of support and data interoperability. Likewise, knowledge generated through scientific review, technical assessment and project implementation is not always systematically captured and shared across the whole consortium and providers, limiting the ability to consolidate the accumulated experience into a durable common asset.

Overall, the current IDRIN model has shown a strong capacity to deliver scientifically excellent and technically advanced access to a broad and diverse user community. Its principal added value lies in the integration of distributed expertise, facilities and services into a coherent research environment capable of supporting complex and ambitious scientific projects. This unique NFFA-Europe/NEP offer in the RI landscape (others attempt only a connection among large scale facilities or established consortia) definitely demonstrates that in the domain of nanoscience and advanced materials science the need of integrated access to top-quality resources from sample synthesis and fabrication to fine analysis and theory is well understood by the scientific community and recognized as an element of the paradigm of contemporary research in this science sector.

At the same time, the analysis highlights that sustaining this level of quality in the long term will require addressing challenges related to scalability, workload distribution, knowledge retention, operational efficiency and harmonisation across the different components of the infrastructure. These considerations provide the basis for the development of sustainable technical and scientific management schemes discussed in the following sections.

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3. Emerging needs for the long-term management of IDRIN

The analysis of the strengths and weaknesses of the current IDRIN operational model highlights that, despite the overall effectiveness of the infrastructure in delivering scientifically excellent and technically advanced access services, several challenges must be addressed to ensure its long-term sustainability. Many of these challenges are not specific to a single coordination component but emerge across multiple areas of the infrastructure, revealing common needs that affect the scientific, technical, operational and organisational dimensions of the IDRIN.

The needs identified in this section originate from practical experience accumulated during the operation of the infrastructure in NEP and reflect both the specific requirements of individual coordination components and broader challenges shared across the entire IDRIN.

Need 1 – Digitalisation, automation and decision-support capabilities

The analysis highlights a common need for a higher level of digitalisation, automation and decision-support capabilities across the entire IDRIN ecosystem. Within the TLNet, the increasing complexity of technical feasibility assessments and workflow optimisation generates a significant workload for the instrument scientists, particularly when similar requests are repeatedly evaluated. UONet identifies analogous challenges in the management of user support activities, reimbursement procedures and administrative workflows, many of which still rely on fragmented and partially manual processes. Furthermore, the scientific evaluation process would benefit from improved integration of proposal histories and review records within the central operational platform and from AI tools as support for the reviewers.

At the same time, all components of the infrastructure would benefit from more advanced monitoring and reporting capabilities. TLNet relies on continuous information exchange between distributed nodes to coordinate technical evaluations and optimise access pathways. UONet highlights the need for real-time monitoring of administrative activities, while data management activities require more systematic KPIs and user-feedback mechanisms to support service evolution. Collectively, these observations indicate the need for an integrated digital environment capable of automating routine processes, supporting evidence-based decision-making, improving coordination among actors and enabling the efficient management of an increasingly complex distributed RI.

The progressive development of machine-actionable descriptions of facilities, services, workflows and operational processes will be an important enabler for automation and decision-support systems.

Need 2 – Acquisition, storage and reuse of FAIR data

On top of all the digitalization needs described above, a strong investment must be dedicated to the FAIRification activities. At present, one of the main limitations is that FAIRification activities are often addressed through horizontal coordination and a limited number of cross-cutting developments, while the actual work needed to adapt metadata schemas, provenance workflows, formats, validation rules and user support to each technique is much more technique-specific: every experimental technique has its own instruments, data structures, conventions and community standards, and therefore requires a dedicated effort for analysis, harmonization, implementation, testing and follow-up, including mapping of data flows, identification of required metadata and provenance elements, adaptation or creation of schemas, alignment with open formats where possible, support for data publication and archiving workflows, and training of the relevant users and instrument scientists.

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Large FAIR datasets generated at NFFA could become part of the service portfolio, particularly for simulation and theory, and promote the reuse of experimental data to accelerate research and reduce duplication.

The development of FAIR protocols for data management and curation should then concern also to RI management and technical data, to enable innovative AI-supported decision-making tools and to create reusable historical datasets for the benefit of the whole RI, also stimulating harmonization and inclusion.

Need 3 – Sustainable allocation and recognition of human resources

A recurring theme across all components is the reliance on highly specialised personnel whose contribution is critical to the quality of the RI services. TLNet highlights the substantial effort required from instrument scientists to perform feasibility assessments and optimise user workflows, often without direct scientific recognition. UONet points to the uneven availability of dedicated administrative personnel across providers, with scientific staff frequently assuming responsibilities beyond their primary role. In the data management area, several key services depend on a limited number of technical experts responsible for FAIR implementation, service maintenance and user support. Similarly, the increasing number of proposals handled pro-bono by the scientific review process places growing pressure on reviewers. These observations indicate the need for management mechanisms that ensure adequate allocation, recognition and long-term sustainability of scientific, technical and administrative personnel involved in the operation of the RI.

Need 4 – Harmonisation across distributed providers while preserving flexibility

As a distributed research infrastructure, the NFFA-Europe IDRIN continuously balances harmonisation and local autonomy. The TLNet seeks to ensure consistent technical evaluation procedures across a large network of facilities while exploiting the diversity of available expertise and instrumentation. The UONet faces similar challenges in harmonising administrative and user-support practices across institutions operating under different legal and organisational frameworks. Data management activities must pursue consistent FAIR practices and interoperable services while accommodating the specific requirements of individual scientific techniques. These observations highlight the need for an operational model capable of promoting impartial and homogeneous harmonisation and interoperability without compromising the flexibility required by local conditions and scientific diversity. This can be supported by the development of agnostic digital tools based on a large set of historical FAIR data including both technical specs of the instrumentation (machine actionable catalogue) and operational data of the RI. From the administrative point of view, the existence of different legal frameworks prevents full harmonisation, nevertheless centralization of the reimbursements as well as the creation of a single Legal Entity would simplify the overall management.

Need 5 – Long-term sustainability beyond project-based operation

A final overarching need concerns the long-term sustainability of the entire infrastructure beyond the duration of individual projects. The current operation is based on INFRA(SERV) projects that cannot support further developments nor a long-term activity. The current funding mechanism revealed useful but rigid with respect to possible further extension of the providers' network and not flexible enough. Currently, the involvement of providers external to the Consortium is possible but only via the Third Party against Payment scheme, which cannot allow a quick and efficient answer to the, a-priori unpredictable, users' needs. Furthermore, TNA EU-funded projects exclude the national research communities, thus reducing in particular the interaction with the innovation system that most of the times work at local or regional levels. The future IDRIN management schemes

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should therefore not only ensure operational efficiency but also provide stable governance, financial sustainability and continuity of services beyond individual funding cycles, with flexible and not fixed funding and capacity allocation to the RI nodes according the user demand and technical availability.

4. Path towards a sustainable model

The emerging needs identified in the previous section highlight a set of key areas that must evolve to ensure the long-term sustainability of IDRIN. A transition towards a more resilient model requires several structural, organizational and technological developments aimed at improving scalability, reducing operational complexity, preserving scientific quality and ensuring continuity beyond individual project funding cycles.

The relevance of these developments is further reinforced by the recent inclusion of NFFA2050 in the ESFRI Roadmap 2026. This milestone recognizes the strategic importance of the NFFA vision for the future European research infrastructure landscape and provides a long-term framework for the evolution of IDRIN. Several of the concepts underpinning NFFA2050 — including FAIR-by-design data management, AI-supported orchestration of resources, digital twins and hybrid research workflows — are closely aligned with the sustainability pathways identified in this deliverable.

4.1 Establishment of a Permanent Legal and Governance Framework

A fundamental step towards long-term sustainability is the establishment of a permanent legal and governance framework for the infrastructure. The current operational model relies heavily on project-based coordination mechanisms, which have proven effective for developing and validating the IDRIN concept but provide limited guarantees for long-term continuity. Several components of the infrastructure, including user support services, data management activities and technical coordination functions, require stable governance arrangements, clear accountability mechanisms and sustainable resource allocation. The establishment of a legal entity would provide the organizational basis for maintaining services, coordinating distributed providers, engaging Member States and ensuring the long-term operation of the infrastructure independently of individual project cycles. Different options are considered: before going for the well-known ERIC process, a more flexible EGTC (European Grouping for territorial Cooperation) model is being considered. The EGTC is widely used at European level and well-known at national governments and funding agencies although never applied so far in the research environment.

This step is currently starting and will be reached in the course of the Preparatory Phase envisaged for NFFA2050 as ESFRI project in the 2026 Roadmap.

4.2 From FAIRification to FAIR-by-Design and alignment with EOSC

The experience gained in FAIRification activities demonstrates both the value and the complexity of implementing FAIR principles across a distributed research infrastructure. Future developments should at least partially and progressively move from FAIRification as a corrective activity applied after data generation towards a FAIR-by-design approach in which metadata standards, provenance information, interoperability requirements and data-management practices are embedded directly into research workflows, instruments, services and access procedures. Such an approach would improve data quality, reduce manual effort and create the machine-actionable information layer required for future advanced digital services. All the development should take stock and align with good practices and current efforts at institutional, national and European level for an efficient optimization of resources and technical solutions. FAIR data management and curation will need to be align with EOSC to populate the European data spaces and contribute to EOSC services in collaboration with thematic and national EOSC nodes.

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4.3 Building a Machine-Actionable Infrastructure

The growing complexity of the infrastructure highlights the need for a transition from human-centred coordination to digitally supported orchestration of resources. This evolution requires the progressive development of machine-actionable catalogues, standardized metadata, structured knowledge repositories and interoperable digital services capable of representing facilities, instruments, capabilities, workflows and access processes in a form that can be automatically queried and processed. Such a digital layer would constitute the foundation for future intelligent services supporting technical feasibility assessment, access planning, capacity management and user guidance.

4.4 Development of an Integrated Digital Ecosystem

Although significant progress has been achieved through the implementation of the Single Entry Point, monitoring tools and FAIR data services, several operational processes remain fragmented across different systems and actors. A sustainable model requires the gradual integration of technical, scientific, administrative and data-management functions within a coherent digital ecosystem. Proposal management, scientific evaluation, technical assessment, user support services, access monitoring, data stewardship and reporting activities should progressively become interconnected elements of a common information environment capable of supporting the entire lifecycle of user access and infrastructure management.

4.5 Building a Shared Infrastructure Knowledge base

Building "institutional" memory at RI level requires the progressive transformation of individual expertise into shared infrastructure knowledge. Proposal histories, technical assessments, reviewer reports, access workflows and best practices should be systematically documented and integrated into common repositories. This process will ensure knowledge continuity across the infrastructure and provide the foundation for future machine-actionable and AI-assisted services.

5. The proposed sustainable model

The sustainable IDRIN model envisioned from the analysis presented in the previous sections is based on the preservation of the key strengths of the current infrastructure while reducing the dependence on highly manual processes and fragmented operational workflows. The model combines human expertise, FAIR-by-design data practices and advanced digital services to create a scalable and sustainable research infrastructure capable of supporting an expanding user community without compromising scientific and technical quality. This approach is closely aligned with several core elements of the NFFA2050 vision.

5.1 FAIR-by-Design Infrastructure and Machine-Actionable Resources

A fundamental characteristic of the sustainable model is the adoption of FAIR-by-design principles across all infrastructure activities. Experimental data, metadata, provenance information, facility descriptions, instrument capabilities and operational procedures are generated and maintained in machine-actionable form from the outset of the research process. Retrospective FAIRification could be applied to legacy datasets to increase the overall volume of FAIR datasets or in those cases where FAIR-by-design solutions are hardly applicable. This approach ensures that information produced throughout the access lifecycle can be directly reused by researchers, infrastructure services and advanced digital tools. The resulting ecosystem enables the systematic exploitation of accumulated knowledge and establishes the information layer required for intelligent resource orchestration and automated support services. Materials science is not a "big data" domain therefore a tailored usage

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of AI must be applied, which implies that the limited size of the data must be compensated by "completeness of annotation, high quality, high fidelity, cleanliness" of the generated and curated data to really enable useful application of advanced statistical algorithms.

5.2 AI-Assisted TLNet with Human Supervision

In the sustainable model, the Technical Liaison Network remains the technical pillar of the infrastructure, but its operation is augmented by artificial intelligence tools capable of supporting feasibility assessment and access planning. Technical evaluations are assisted through the analysis of machine-actionable descriptions of instruments, techniques and facility capabilities, combined with information derived from previously successful access workflows, datasets and completed projects. Understandable AI tools can identify potential access pathways, suggest suitable facilities, detect technical incompatibilities and propose optimized work plans. Final decisions, however, remain under the responsibility of the scientific and technical experts of the TLNet, ensuring that human judgement continues to govern all critical aspects of access evaluation and planning.

5.3 AI-Assisted ARP with Human-Led Scientific Evaluation

The Access Review Panel similarly benefits from AI-supported services while preserving the primacy of peer review. Intelligent tools may assist reviewers by identifying proposals with similar scientific objectives, retrieving relevant information from previous evaluation cycles, analysing proposal portfolios and supporting the assignment of reviewers according to expertise. Such tools can improve efficiency, reduce administrative workload and facilitate the management of increasing proposal volumes. Nevertheless, scientific merit assessment remains a responsibility of the reviewers and of the ARP as a whole, which continue to exercise independent scientific judgement in the evaluation and ranking of proposals.

5.4 Machine-Actionable Knowledge Base

The sustainable model relies on the creation of a continuously evolving knowledge base integrating information generated throughout the operation of the infrastructure. Proposal histories, reviewer reports, technical assessments, access workflows, datasets, metadata, facility capabilities and usage statistics become part of a common historical track record. This knowledge base reduces dependency on individual experience, facilitates knowledge transfer between generations of reviewers and facility staff, and provides the foundation for future digital services. It also allows the infrastructure to capitalize on the expertise accumulated through years of operation and transform it into a shared strategic asset.

5.5 Hybrid Research Workflows and Enhanced Digital Services

The future model extends the concept of access beyond physical visits to facilities by integrating digital services, including digital twins of the instruments, directly into hybrid research workflows. Physical access, digital twins, data analysis services, simulation tools, machine-learning applications, remote support services and FAIR data repositories become integral components of the access offer. Users can combine physical access to installations with remote interactions and digital resources, creating hybrid research workflows that maximize scientific value while reducing operational burden. Such an approach also facilitates participation by a broader and more geographically diverse user community.

5.6 Reduced Mobility and Optimised User Travel

The availability of advanced digital services, reusable FAIR datasets, remote access capabilities and AI-supported planning tools enables a reduction in the amount of travel required to complete a

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research project. User travel becomes focused on activities that genuinely require physical presence at the facility, whereas preparatory work, data analysis, training activities and follow-up interactions can increasingly be performed remotely. This approach reduces costs, simplifies logistics and contributes to the environmental sustainability of the infrastructure while maintaining the scientific effectiveness of access.

5.7 Centralised Reimbursement and Simplified User Support

Within the sustainable model, travel and subsistence reimbursement activities are centralized under a single organisational entity responsible for managing all user reimbursements, independently of the access location. This approach eliminates many of the administrative inefficiencies associated with distributed reimbursement procedures and provides a more uniform user experience across the infrastructure. Local UONet nodes continue to play an essential role, but their activities focus primarily on local logistics, reception services, practical support and interaction with users at the facility level. The separation between central financial management and local user support simplifies workflows, clarifies responsibilities and improves overall operational efficiency.

6. Conclusions

The analysis presented in this deliverable shows that the current IDRIN model has successfully demonstrated the feasibility and scientific value of operating a distributed and interoperable research infrastructure for nanoscience, and has fully served the successful operation of all NEP activities. The strengths identified in the operation of TLNet, UONet, ARP and Data Management confirm the effectiveness of the current approach, while the weaknesses and emerging needs highlight the areas that must evolve to ensure long-term sustainability.

The proposed sustainable model builds upon the existing foundations of the NFFA IDRIN while introducing a stronger integration between FAIR-by-design data management, machine-actionable infrastructure descriptions, AI-assisted coordination mechanisms, hybrid research workflows and streamlined administrative processes. In this model, human expertise remains central to scientific evaluation, technical decision-making and user support, while advanced digital services provide the scalability and efficiency required to support future growth.

The transition towards such a model requires the progressive implementation of the actions identified in the *Path Towards a Sustainable Model*, including the establishment of a permanent governance and legal framework, the development of integrated digital services, the consolidation of institutional knowledge and the creation of machine-actionable infrastructure resources.

Ultimately, the long-term sustainability of the NFFA IDRIN will depend on its ability to preserve the scientific excellence, technical expertise and user-oriented approach that characterize the current infrastructure, while exploiting digital technologies to improve efficiency, interoperability and resilience. Under these conditions, the IDRIN can evolve from a project-driven distributed infrastructure to shape the core of a long-term sustainable European research infrastructure capable of supporting future generations of nanoscience users and providers in a more and more interconnected resource space.

The inclusion of NFFA2050 in the ESFRI Roadmap 2026 demonstrates that the evolution pathway outlined in this deliverable is not only responsive to the needs emerging from the current IDRIN experience but is also aligned with the long-term European vision for distributed research infrastructures in nanoscience embracing the broad domain of quantum and advanced materials, providing unique research solutions tailored to curiosity driven research as well as to innovation driven developments.

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