EPOS ERIC

EVALUATION OF THE EPOS ERIC ACTIVITIES 2019 - 2023

EUROPEANPLATEOBSERVINGSYSTEM

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EVALUATION OF THE EPOS ERIC ACTIVITIES 2019 - 2023

Report by the External Evaluation Panel

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Contents

Foreword

This document summarizes the findings of the External Evaluation Panel (EEP) following a scientific and technical evaluation of the activities of EPOS ERIC during its first five years of initial operations (2019-2023). This phase started as a testing phase in 2018 and transitioned into the pilot operational phase (2020-2023). It has been devoted to developing the requisite procedures and policies, to building up the capacities of EPOS structural elements (ECO, ICS, TCS, ICS-C, ICS-D, see the Glossary of the Terms of Reference, Appendix 1) and to strengthening their interactions and governance.

In accordance with its Terms of Reference (Appendix 1), the EEP has evaluated the readiness of the infrastructure for operation, considering that during its first five years, EPOS ERIC has been active in the implementation and pre-operational phases.

The evaluation has taken place during the year 2023.

Executive Summary

ERIC EPOS has successfully achieved a remarkable milestone since its inception, the operational readiness which has been the goal of the implementation and pre-operational phases between 2019 and 2023.

From a scientific perspective, EPOS has shaped its infrastructure services such that there is now a foundation for enabling the European Solid Earth Science to achieve scientific excellence and innovation in novel ways crosscutting all subdisciplines and reaching new untapped scientific communities.

EPOS has tested and successfully implemented suitable policies and tools to guarantee open science which rest on a very clear user strategy and policy. However ahead of it, EPOS has a formidable task of increasing awareness and knowledge of EPOS in the wider Solid Earth science community.

EPOS has already demonstrated during the pre-operational phase its pan-European and global relevance, which will enable growth and increasing traction in the scientific community.

EPOS has further enabled new scientific communities to set up and organize thematic services that are of high socio-economic impact which attests to EPOS successful design and implementation. It is indeed of high importance for EPOS to capture and quantify its successes in relation to socio-economic and technological impacts. Defining metrics that demonstrate its impact in the domains of science and innovation, as well as technology and socio-economic domain will help underpin its long-term sustainability.

In terms of financial sustainability, its membership comprising governmental administrations has a more mixed record of accomplishment. While their commitments are in principle very high, there is a shortfall in regard to the allocation of actual financial resources from a large majority of members' governmental administrations when compared to the intended nominal financial resources, even from countries with a high per capita GDP, and this is not sustainable in the longer term.

Nonetheless, EPOS is characterized by an excellent governance structure; an efficient and effective management embodying core values of service to the scientific community, transparency, as well as thrift and efficiency; and a human resources policy that highly appreciates and extracts high added value from being diverse.

In sum, EPOS is run very well and is well suited to managing its delivery and operations framework. A feature of EPOS high performing management is a meticulous attention to EPOS risk profile and managing it accordingly. Risk management policies as well as their implementation in planning, execution, checks (quality assurance and control), and review processes with results shaping the risk profile, are of very high quality. The panel has recommended a number of measures; in the domain of scientific excellence and innovation suggestions target wide uptake of EPOS in the Solid Earth science community by expanding EPOS portfolio of services and products. When it comes to the user strategy and policy, measures are proposed to engage users, while the panel proposes developing an approach using key performance indicators to credibly demonstrate in a semi-quantitative manner, EPOS' socio-economic and technological impact, and stakeholder commitment. Importantly, the panel strongly encourages the entire EPOS membership to demonstrate their commitment and to fully enable EPOS to live up to its potential by contributing their nominal membership fees to ensure the optimum value generation from EPOS Thematic Core Services.

1. Introduction

The document summarizes the findings of the External Evaluation Panel's (thereafter, the panel) scientific and technical evaluation of the activities of EPOS ERIC during its first five years of initial operations (2019-2023).

The evaluation was initiated in March 2023, formally kicked-off on 11 May 2023, and concluded in November 2023 via an iterative process of virtual and physical site visits, document and presentation review, responses to panel questions and panel discussions.

During the months of March and April 2023, the EPOS Executive Coordination Office set up an IT environment that included the provision of full access to EPOS documentation relevant to the evaluation and creation of a virtual space for collaboration among the panel. The virtual space was developed dynamically and with the full and unbridled support of EPOS' Executive Coordination Office.

The evaluation kicked off with a half-day preparatory meeting held virtually on 11 May 2023. The panel discussed with the EPOS Executive Coordination Office the Terms of Reference and the way of working between the panel and the EPOS Executive Coordination Office. The Terms of Reference were subsequently agreed upon and issued by the General Assembly of EPOS (Appendix 1). Based on the presentations (Appendix 2) and the discussions held during 11 May 2023, as well as a comprehensive list of background documentation (Appendix 2) which was presented on 12 May 2023, the panel compiled a commentary on the initial set of data and information. This commentary included a request for additional information covering the points of issue described in the Terms of Reference.

The EPOS Executive Coordination Office subsequently organized and hosted a physical and virtual meeting and site visit at its physical offices at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome on 13-14 June 2023. The site visit comprised a series of eight presentations (complemented with a number of sub-presentations given by various Thematic Core Services) addressing points of issue. Part of the site visits were detailed discussions on 13 June 2023, as well as a dedicated meeting on 14 June 2023 with the panel where key actors of the EPOS Executive Coordination Office and representatives from service committees provided answers to specific questions of the panel.

The panel produced a draft evaluation report which was discussed on 15 October 2023 with the EPOS Executive Coordination Office. The evaluation was finalized on 1 November 2023.

The panel finds it noteworthy that all contributors and interlocutors of EPOS ERIC participated fully and openly at both engagement sessions, that responses were consistent with one another and that issues raised in the panel's initial commentary had been studied in detail with additional data and information presented and discussed during the physical site visit. The EPOS Executive Coordination Office prepared all responses to additional questions put forward via e-mail, immediately and comprehensively. The panel finds the focus, transparency and dedication to delivery of the EPOS Executive Coordination Office equally noteworthy and highly commendable.

Our overall conclusion is that EPOS ERIC is a top performer among its peers in the ERIC landmark landscape.

After setting the context within which EPOS ERIC operates, the outcome of the evaluation is outlined below, under headers corresponding to the points of issue described in the Terms of Reference.

2. EPOS ERIC in the Wider Context of European Research Infrastructure Consortia

ESFRI (European Strategy Forum on Research Infrastructure) projects followed by landmarks, commenced around 2009 when the first roadmap had been released. At the time awareness had increased that distributed infrastructures to foster access to distributed data, facilities and services would be as important as centralized infrastructures for high-quality research and new insights. In addition, technological developments made it possible to think of Open Science as an addition to Open Publishing which was facilitated by cost-effective printing options centuries ago. All kinds of research artifacts (data, metadata, software, semantic assertions, etc.) were seen as important to share. However, at the beginning, no one knew exactly what the term "research infrastructure" would include.

With the knowledge of today, we can state the following key points for the ESFRI projects/landmarks, and in particular the distributed ones:

- They deliver joint services such as aggregating portals and foster harmonization where possible in scientific domains,
- create awareness in the broad research community about the opportunities due to modern technology, in particular, the principles of Open Science and FAIR data,
- structure the domain of research data and services in which the corresponding partners are active, i.e., strengthen the role of data creation and management centers,
- address different stakeholders (funders, e-Infrastructures, early career people, etc.) on the way towards the digital transformation, and
- identify solutions to foster sustainability[1].

The major challenges, especially in the early phase, were organizational and social; bringing together expert communities of different background and subfields and convincing them to not only think of their own goals and their direct customers but to start opening up to address broader communities. Hence, there are structural commonalities among many ESFRI ERICs:

- At the top one finds an aggregation layer organized by the ERIC,
- in a second layer one finds data creation, management and analysis organized by centers/laboratories (mostly national, some of which also function as aggregation layer within sub-fields)
- and in a third layer there are the individual researchers in their respective administrative units.

[11] In periods of high dynamic changes as in the domain of "digital infrastructures", also the sustainability needs to evolve following the dynamics.

While many ERICs in fact managed to achieve a close interaction within the second layer, in a number of cases it was not easy to address the individual researchers by added-value services.

A second observation which emerged from the many years of work within the ESFRI ERICs is that early dreams of a fast transformation towards FAIR principles (findability, accessibility, interoperability, and reusability) have been replaced by a more realistic view that this transition will take more time since all of the existing entities would have to invest additional resources to adapt their data models and procedures.

Within the environmental domain, there are eight landmark ERICs (implemented or at advanced stages of implementation) and three projects (research infrastructures in preparation), EPOS ERIC is the only ERIC landmark in the environmental domain that is rooted in the Solid Earth sciences. EPOS ERIC is a distributed research infrastructure.

3. Scientific Part of the Evaluation

3.1. Scientific Excellence and Innovation

EPOS ERIC involves essentially all major scientific players of the Solid Earth Sciences in Europe and covers virtually all areas of research in the Solid Earth sciences.

The gateway to EPOS ERIC is the EPOS portal which has recently been successfully launched and is now operational. This portal, dedicated primarily to data access in a wide range of disciplines, is currently the foremost raison d'être and purpose of EPOS, and credibly enables innovative research. In addition to providing data sets in the ten scientific domains covered by the Thematic Core Services (TCS), the portal offers useful possibilities that go beyond those that are available in sub-discipline specific data sharing initiatives. For example, when compared to GeoMapApp, an easy-to-use application that can be installed on a laptop, EPOS gives access to very different additional sources of data such as geological maps, borehole data, seismograms or GPS positioning series. The portal thus allows the user to build synthetic data sets and images, in 3D, on a given region with only a few clicks, and allows for multidisciplinary developments.

Thematic Core Services (TCS) are the vehicle to foster scientific excellence via integrated, cross-disciplinary research. The thematic communities interact through the Service Coordination Committee which provides a strong link to EPOS' management. The present-day TCS in the different scientific domains interact successfully and closely with the central organization of EPOS. The procedure to integrate new topics and create new TCS is well designed and efficient (see the new TCS dedicated to tsunamis). Currently ten in number, the maturity of TCS covers the entire spectrum of nascent/in-preparation (e.g., Built Environment Data), candidate (e.g., Tsunami), mature (e.g., Global Navigation Satellite

Systems, GNSS, or Seismology) thematic core services. The different levels of TCS maturity are commensurate with that of their respective communities; for example, the GNSS and seismology communities have a long-standing record of having been well organized at the international level. Efforts have been made to attract new communities that are obviously important for the interest of research in the Solid Earth research community, such as gravity and magnetism (rock magnetism, including paleomagnetism and the magnetic structure of the crust and lithosphere, active geomagnetism being covered by a dedicated TCS). This positive effort should be continued until these communities are convinced of the importance of integrating the Solid Earth community at the European level. Excellent is the novel Near Fault Observatory TCS which exemplifies the integrated, cross-disciplinary virtual laboratory that EPOS ERIC has been able to set up. Here, multidisciplinary data and production, some from other TCS are analyzed, interpreted and used to develop tools for early warning systems for earthquakes. With regards to the Multi-Scale Laboratories TCS, the expert panel was not entirely convinced by potential outputs and outcomes of the integration of widely ranging experiments from, for example, analogue modeling labs or High Pressure – High Temperature experiments in the TCS; no convincing evidence has been provided on the portal to date (the portal is almost empty in these two cases) and the future evolution of these parts should be monitored to achieve success. EPOS demonstrates already today structural contributions to internationally competitive research (e.g., the Near Fault Observatory TCS).

The expert panel views the future success of EPOS in terms of scientific excellence to depend on the additional services that the EPOS portal will offer, ideally in the near future; services that are beyond access to databases and downloading facilities. EPOS faces the major challenge of being a relatively small structure in charge of centralizing data from many organizations that are much bigger and have more resources available. The expert panel expects the need for these kinds of services to become key to EPOS' success once databases have been sufficiently alimented with data. The level of suitable richness of datasets accessible on the EPOS portal, however, is far from reality today, except in a few domains (GNSS or seismology).

The upside of delivering analytical routines or applications once integrated in the portal is significant. They will provide user-friendly ways of managing and processing large amounts data and allow for new scientific insights to be made. Providing access to additional services that, for example, enable complex calculations on large amounts of data, even for geologists not specialized in coding, would be a major step forward. However, such a provision is a major challenge for EPOS considering the available limited resources. Instead, end-users may in the interim upload quality-controlled and quality-assured routines or programs in the EPOS portal to implement scientific applications through such a collaborative approach. A user-friendly "blockbuster generic mapping toolbox (GMT)" is such an example, or a user-friendly interface with existing GMT.

We draw the following main conclusions in regard to scientific excellence on EPOS:

- EPOS succeeded in raising awareness about the paramount role of data, the need to improve its FAIRness (findability, accessibility, interoperability, reusability) in the broad Solid Earth science community and the need to improve data quality.
- EPOS succeeded in bringing many data centers from a wide range of different sub-fields together to unlock much data hidden in institutional servers, in agreeing to develop common strategies and reduce fragmentation, to take steps in harmonization such as determining a convincing metadata strategy to enable flexible aggregation.
- In so doing, EPOS created a huge potential to improve data driven research which will have its impact in the coming decades where data will not only be used within domains but also across domains. The example of early warning earthquake systems indicated this potential convincingly.
- As a preparation for the operational phase, EPOS created an operational portal which offers many features enabling researchers to quickly visualize relevant phenomena coming from different research areas and sub-fields, and to inspire researchers to look in more detail into specific patterns. The utility of the portal as a vehicle to engage citizen scientists was clearly demonstrated.
- EPOS can be seen as one of the most successful ESFRI ERICs although there are still challenges for the coming phase, which lead to the following recommendations:
    - the need and wish to add value-adding services for end-users (see below for some specifics),
    - the need and wish to unlock even more data still hidden on servers of research institutions and laboratories,
    - continued joint efforts to find financial resources to improve data FAIRness and quality,
    - open up a repository to include the long tail of data of the field (which includes for example derived data) even if data quality is not evident or if metadata quality is poor.

Added-Value Services: with respect to value-adding services, EPOS very clearly and convincingly explained the need to offer flexible workflow mechanisms via the portal with the idea that users can a) create virtual collections of data, b) orchestrate operational steps into workflows and c) execute those workflows using high performance computing, for example. While this goal is timely, experience from other ERICs (ELIXIR Galaxy, CLARIN Weblicht) suggests that it is not trivial to define an appropriate strategy and implementation. Galaxy, for example, offers 3 layers: (1) a generic workflow tool for experts with programming skills which is comparable to using Jupyter notebook as indicated by the EPOS experts, (2) an intermediate layer where trained users can orchestrate their workflows by integrating ready-made building blocks and (3) finally

ready-made workflows for recurring tasks for the lay user. Developing such a framework incurs an enormous effort spread out over many years.

Level of database population: it is urgent to feed databases in all the TCS to make EPOS visible and productively useful. The launch of the portal will likely generate new momentum in the community of Solid Earth sciences if the power of that tool is understood; a portal where all sorts of data, with quality indicators, are available just a few clicks away. The portal will moreover foster more interdisciplinary studies because of the possibility of finding a wide range of data on the same website.

A potential lack of motivation of some Solid Earth science communities to integrate into EPOS might stem from fear of individual researchers being hidden behind the EPOS banner and not being recognized for their own work in data acquisition. It is thus of prime importance to design procedures forcing EPOS users to cite both the data providers and EPOS in their publications. Communicating that original works are duly acknowledged and that EPOS is an open window for individual contributions as well as a strong infrastructure for data synthesis are among the prerequisites for attracting more researchers to utilizing EPOS.

The expert panel also recognizes that individual researchers continuously invent new analytic algorithms to detect specific phenomena. EPOS with its workflow framework is well positioned to continuously incorporate useful new analytic tools. Therefore, EPOS should organize workshops with experienced experts to identify promising approaches and be a testbed for timely evaluation of pilots and prototypes.

With regards to the operation of its infrastructure dynamics, EPOS has successfully structured its domain and thus has built a strong federation of centers and data providers. Due to industrial influences “federations focusing on data” have been coined “dataspaces” in recent decades. EPOS is in a strategically excellent position to participate in any European activities, while communicating clearly the “dataspaces” created by EPOS and building on federated technologies and rules which are optimally suited for the Solid Earth research domain. Many such dataspaces have been built during the last decades and there will be an increasing pressure to achieve interoperability between these different dataspaces. EPOS, as one of the strong actors, should participate in the discussions and ensure that the domain interests are considered.

3.2. User Strategy and Policy

Framed by its statutes, EPOS ERIC has in place comprehensive access policies (data policy and digital assets management policy) that govern access of EPOS users. The timely successful launch of the EPOS portal dedicated to data access in a wide range of disciplines is a key purpose of EPOS in its relation to its users. The successful launch of the EPOS data portal has strongly benefited from a successful co-creation process that has involved IT specialists and the respective topical communities populating the Thematic Core Services (TCS). Extensive testing was undertaken with user feedback groups and online training sessions. The user's perspective is very much at the heart of the EPOS portal. There is an operational single entry for access to the EPOS portal for the user. The entire approach is excellent and serves as an excellent foundation for subsequent operational phases.

However, there is still a general lack of awareness and knowledge of EPOS in the broader community of Solid Earth (and other) scientists who have not yet put EPOS on their mental maps with respect to persistently excellent scientific research output of the entire European Solid Earth science community. Considering the only very recent opening of the portal, this is not surprising. Still, today EPOS already has a higher and positive visibility in the seismology and GNSS communities because they already experienced the importance of being united and federated.

Efforts have been made to attract new communities that are important for the interest of research in the Solid Earth community, such as gravity and magnetism (rock magnetism, including paleomagnetism and the magnetic structure of the crust and lithosphere, active geomagnetism being covered by a dedicated TCS). EPOS is encouraged to build on core disciplines within the Earth Sciences domain. This positive effort should be continued until these communities are convinced of the importance of being part of the Solid Earth community at the European level.

Highly commendable are the efforts of EPOS to continuously expand its user communities by not only growing communities in established TCS, but also maturing communities with a view towards developing new TCS. The relevant processes are structured, planned and are thus readily and systematically executable.

The self-evaluation of EPOS' user strategy and access policies is deemed appropriate by the expert panel. For EPOS' operational phase, the EEP particularly recommends:

- the need for a well-thought through dissemination strategy and, above all, a sound implementation of the strategy to achieve a high level of awareness and knowledge of EPOS' capabilities in the Solid Earth science community towards achieving scientific excellence;
- the need for a comprehensive user strategy for the exploitation of the EPOS portal: to demonstrate the added value to the end-users, EPOS needs to develop a user strategy

where the usage of the portal will be central. EPOS may explore ways to incentivize the use of the EPOS portal via prizes for early career researchers who use the portal;

- the need to spend considerable efforts in training courses on portal usage in and by all participating sub-communities and centers considering the very recent operationalization;
- the need for a pre-defined role of EPOS when it comes to data licensing within a comprehensive IPR framework;
- the need for key performance indicators (KPI) that measure and quantify user uptake.

3.3. Policy Pan-European and Global Relevance

EPOS is the only ESFRI landmark dedicated to Solid Earth sciences within the environmental domain of the ESFRI landscape. Its unique position at the European level is well mirrored in national roadmaps for research infrastructures with at the time of writing 18 European countries having national infrastructure roadmaps, of which sixteen have included EPOS. EPOS is actively growing by successfully pursuing membership of European countries that have not yet joined. EPOS is in the respective national roadmap, which also is helpful for the sustainability of the EPOS landmark. The geographic coverage spans the entire continent of Europe thus reflecting all tectonic regions relevant for the EPOS Solid Earth science domain. Virtually all significant players in the Solid Earth science domain are represented, most importantly the major geoscientific research organizations across Europe. This is in excellent agreement with the EPOS strategy, unique position and relevance as the sole research infrastructure dedicated to the Solid Earth sciences. While efforts to develop applied or engineering-related Thematic Core Services (Built Environment Data TCS) are highly likely to increase the pan-European relevance of EPOS, the panel suggest, however, that efforts need to be balanced with those that result from the growing need to increase EPOS visibility and relevance to the entire Earth Science community.

EPOS is very well positioned and successfully collaborates via dedicated focus groups with other ESFRI landmarks and projects, but importantly also with other transnational data, information and modeling platforms. Importantly EPOS has mapped out a clear path going forward in strengthening those relationships and cultivating new ones (e.g., disaster risk management at EU level) in the coming years of operations.

In terms of global relevance, EPOS is communicating, associating and cooperating with like organizations in Australia and North America which attests to a growing global relevance. Examples are the already established modes of interactions and planned collaboration with global communities, such as the Global Tsunami Model, the Global Earthquake Model, the World Organization of Volcano Observatories) and regional

communities in Australia (AuScope) and the USA (EarthScope, Rupture and Fault Zone Observatory).

However, closer to home, EPOS has not yet permeated the entire set of communities of Solid Earth scientists. This might be due to the very recent opening of the portal, for a large part. But EPOS is not yet well known among a large part of the potential users, or even, in some anecdotal cases, considered as a bureaucratical organization with unclear purpose. This somewhat negative view among some Earth scientists is expected to change drastically once the portal and its enabling capabilities become more widely known. A highly positive view of EPOS is already present in the seismology and GNSS communities owing to their first-mover experience and value of being united and federated. It is thus urgent to populate databases, tools and methodologies in all the TCS to make EPOS visible and maximize its relevance across Europe.

Some countries, particularly those hosting the EPOS executive coordination office (Italy) and the Integrated Core Services (UK, France), and those countries with leadership in Thematic Core Services (e.g., Portugal, The Netherlands, Switzerland, France, Italy) are deeply involved and instrumental in the building of the database, other countries are strong contributors. The involvement of the various European countries is very uneven and largely determined by the availability of resources, both human and financial as well as subject to the challenges of navigating complex national administrations (Ministries of Sciences, Research and Education; of the Environment; of Energy; of Defense, and so on) to ensure broad consistent engagement.

There are a number of opportunities to improve EPOS visibility and relevance. For example, EPOS has processes in place that may open up EPOS to act as a vintage data repository; energy companies, particularly in the upstream hydrocarbon exploration and production sector have acquired during the last decades hundreds of thousands of kilometers of high-resolution seismic profiles. Such data are fundamental for the understanding of the crust structure and hence for modelling tectonic processes and thermal structure of the crust, on short (earthquakes, geothermal energy, lithium, native H2) or long term (rifting, mountain building, ore deposits). The data would be an immense treasure for academic research and EPOS may use its unique position in Europe to negotiate, with data owners, data sharing and utilization agreements.

Another example to increase pan-European relevance is for EPOS to ensure that research and innovation funding agencies, at national and European level, mention the use of EPOS ERIC in call documents. This is the practice, for example, in the 2023 Clean Energy Transition Partnership call documentation where consortia are encouraged to gain access to and use relevant research infrastructures, such as ERIC ECCSEL.

3.4. Socio-economic and Technological Impact

In light of the big transformation to a digital open science domain ahead of us, the impact of EPOS (and a few other similarly excellent ERICs) cannot be rated high enough. Many of the effects are rather implicit than explicit and thus are difficult to quantify. EPOS has demonstrated that (1) building the aggregation layer with all its effects (see 3.1) is possible if significant efforts are undertaken, especially socio-political ones. (2) EPOS has also demonstrated that steps towards FAIRness are best managed and executed as a joint effort and the transition will take more time than expected. (3) EPOS further underlines the fact that unlocking data for the benefit of researchers requires an impulse as was given by the ESFRI initiative and (4) an integration at European level will bring huge benefits for the end user. It is this knowledge build-up and generation by "doing" that will have a long-lasting impact which will be important to take the next steps to come to a globally integrated dataspace based on horizontal cross-cutting technologies.

In addition, EPOS helped changing practices in the various data centers participating in the ERIC, i.e., not all the different data centers had to re-invent the wheel (defining a metadata process and semantic mapping mechanisms, harmonizing data structures, defining rules of participation, etc.). The overall reduction in costs cannot be quantified, but it saved funds which thus became available for alternative investments.

Also, as already indicated, the existing portal has the potential to attract, for example, citizen scientists in areas of broad interest. EPOS should now look for measures to engage the broad public in using this portal and implement ways that allow the public to participate in adding data and information.

The technological impact cannot be addressed by asking for the implementation of new technologies, since building robust infrastructures needs to rely on well-understood and operational software. The technological impact can be found in the mechanisms that were built to make this large federation work, and to configure components that helped achieve the excellence of the EPOS portal. The required effort for developing standards effort should not be underestimated.

EPOS should make sure to design a procedure to force the users to cite both the data providers and EPOS in their publications.

The expert panel recommends the development and use of metrics to measure the real impact of EPOS; such KPIs (key performance indicators) may include the number of downloads once systems are fully established.

4. Evaluating the Implementation

4.1. Stakeholder Commitment

Considering the distributed nature of this landmark, EPOS ERIC has achieved a most impressive record. With a total of 143 European research organizations that are formally involved in EPOS, approximately 250 research organizations that provide data on which EPOS products are built, there is very strong content-related stakeholder commitment to EPOS, its executive committee, the service providers and organizational structures. This is very impressive.

With respect to financial commitments EPOS has demonstrated, well above its expected call of duty, excellent value for money. Nominal membership fees are currently set in EPOS' Statutes (Annex II) at €4.4 mln per year, a target figure which includes countries which are not yet members of EPOS and is used to calculate the country's nominal membership. Currently, the sum of the nominal membership fees to be derived from EPOS' current membership amounts to €2.6 mln per year. However, the sum of actual contributions by countries amounts to €1.9 mln, some 30% below committed numbers. This funding gap is in stark contrast with member's commitments and puts at risk the fully operational nature and sustainability of EPOS.

Added value generation has been well demonstrated to be a core feature of EPOS. The short-to medium term viability of EPOS coordination at the Executive Coordination Office is underwritten and financed by the Government of Italy with EPOS ERIC's membership fees only covering the salary of the Office's executive director. Similarly, the Integrated Core Service's central hub is underwritten by the contributions of the two countries hosting them (Governments of France and the UK) as well as an appropriately significant share of EPOS membership fees. The tie-in of the Thematic Core Services and their sustainability is guaranteed by national funds with a small portion covered by the EPOS ERIC membership fee. The membership fee goes a very long way, and it is of tantamount importance that members honor their commitment and pay the agreed upon fees without discounts.

The EPOS Executive Coordination Office together with key players in the integrated and thematic core services sub-organizations have developed a funding model that rests on an excellent application of the subsidiarity principle. This is excellent and provides the essence of a sustainable funding model. However, this model resting on subsidiarity only works as long as funding bodies are cognizant of the principle and do not unilaterally cancel or diminish their committed contributions.

Considering EPOS' contribution to scientific excellence (e.g., TCS such as the Near-Fault Observatory which strongly leverages EPOS, its portal and a number of more discipline focused TCS) and techno-economic impact (e.g., harmonization of data and implementing FAIR principles), members have to ensure that membership fees contribute to a target contribution of 25% of the TCS operating fees and do not stop at today's 12%. The EEP also notes that the current target contribution to the TCS system benefits from ERIC cash carry-over from prior years. Once the carry-over is exhausted (by the end of 2025 in the current circumstances), the contribution to the TCS would be reduced to 6.5% Currently, there is anecdotal evidence that suggests that not all operating costs of TCS are accounted for but are in fact "labors of love".

When successful and fully implemented, EPOS' growth strategy (more members, more TCSs with a strong focus on societal and economic usefulness) will help realize the funding model.

It is worth emphasizing that for EPOS to attract more funding from the nations involved in the system or directly from the European Commission, there has to be a visible and proven record of accomplishment of EPOS' usefulness and economic added value in particular in national settings. National administrations need to be continuously reminded of the added value of EPOS – in a language that is accessible and comprehensible for administrators and funders.

The expert panel wishes to illustrate this point on, for example, France: France contributes already today significantly to EPOS (RESIF soon to become EPOS-France) in terms of machines and workforce. France is also an important data provider and pays a significant contribution of about €200'000, some €150'000 short of its nominal €350'000 annual cash commitment. Some 111 full-time employees (CNRS, Universities, CEA, BRGM, IRSN, IRD…) contribute to data acquisition and storage before transferring them to EPOS, which amounts to a consolidated total of ~€11 mln per year. Fully appropriately, this is not accounted for in TCS operations because data acquisition is fully in the remit of national research organizations. The financial envelope, however, dedicated to Solid Earth is fixed at the governmental level which implies difficult choices and trade-offs between EPOS cash contributions on the one hand and on the other hand as an example funds for operating and maintaining instrument pools. This tension suggests that EPOS needs to continuously communicate its added value to the French administration to justify the payment of nominal membership fees or even justify higher actual contributions to EPOS.

Sustainable membership fees for EPOS ERIC are essential for the functioning of the operations of Thematic Core Services (TCS) whose infrastructure services are key enablers for scientific excellence and innovation. Not only that: at a national level successful TCS are catalysts for improving the value of investments in science and innovation. Today, EPOS ERIC can contribute no more than 6.5% (respectively 12%, if the temporary ERIC

cash-carry over until 2025 is included) of TCS operations, significantly short of the targeted 25%. It is thus of prime importance for members of EPOS ERIC (1) to have the actual contributed membership fees of all member countries match the nominal membership fees, which are the result of a carefully balanced application of subsidiary finance principles. (2) EPOS ERIC is strongly encouraged to continue in successfully responding to Horizon Europe calls dedicated to research infrastructures and to develop ways of featuring in call descriptions for research and innovation projects that explicitly address the use of research infrastructures (e.g., the Clean Energy Transition Partnership, other Horizon Europe partnerships, and other transnational and European funding instruments). (3) EPOS needs to continue to set as one of its strategic goals an increase of national resources which directly benefit EPOS for an ambitious growth agenda. Reaching this goal requires the successful and clear demonstration of added value for scientific research, technological development, socio-economic impact, and societal benefit. In particular, new significant scientific findings, visible to the public, based on the use of EPOS are an essential ingredient for funding organizations to increase financial appropriations to EPOS.

4.2. Current Status and Planning

EPOS has developed during the period under review an excellent foundation to future growth, continued development and its evolution. There are clear implementation rules that address the development of new thematic core services, new services within the EPOS portfolio, the implementation of highly promising IT developments and finally the continued development and implementation of the Integrated Core Services – Distributed.

EPOS has already developed a program for operations for the period covering 2024-2028 which comprises a science program and the implementation of a sustainability plan. Key will be the activities that target exploitation of EPOS, cultivate multidisciplinary research, add to EPOS' societal value, and – importantly – reinforce EPOS' presence at the pan-European and global level, while strengthening the long-term sustainability of EPOS.

The future of EPOS depends strongly upon the future of the internet in general. While predictions are notoriously difficult, change will be rapid, profound and drastic. The role of artificial intelligence is the great unknown, but EPOS is keenly aware of its potential and is continuously challenging itself to accommodate these changes and use for opportunities for development. Big data approaches, like data mining, deep learning etc., are already part of the daily work of the Solid Earth sciences community (e.g., seismology and space geodesy) and EPOS alike.

4.3. Governance, Management and Human Resources Policy

EPOS' governance of its delivery framework is a well-calibrated and well-balanced system comprising its general assembly, an executive committee, an executive director and her coordination office, a number of boards covering science, ethics and IT, a service coordination office providing strong linkage to the system of thematic core services as well as linkage to the office of Integrated Core Services – centralized. Roles, responsibilities and accountabilities are very well defined. The governance structure functions well with TCS growing in numbers, EPOS membership growing, and an exemplary approach to open communication and transparency. Of considerable value is EPOS capabilities to welcome diverse individuals and organizations and turning diversity into an impressive strength – not only technically and scientifically but also from a viewpoint of equality of chance vis-à-vis gender and backgrounds.

EPOS management and her very lean and thus extremely efficient, Executive Coordination Office are extremely, and far beyond the expected, a customer/client-focused organization. The expert panel has witnessed an outstanding service mentality throughout. At the heart of this exemplary culture lies a strict adherence to rules of procedure and implementation, a highly diligent approach to defining terms of reference for each of the principal services (integrated core services, centralized and decentralized; thematic core services; interface management; sponsored research activities) and – again – strict adherence to policies without exceptionalism.

Overall, the expert panel attests an exceptionally high level of readiness for EPOS' operational phase within its Delivery and Operations Framework.

4.4. Risk Management

EPOS has put in place a comprehensive risk management policy and risk register during its pre-operational phase. Risk management processes (which are exemplary in their breadth and scope), the principal actors as well as their roles, responsibilities and accountabilities are very clearly defined. Main risks and exposures of EPOS ERIC have been identified with barriers to unwanted events as well as contingency measures in case of unwanted events clearly described and – very importantly – continuously monitored with risk registers being formally updated.

The expert panel attests a high and fully appropriate level of skill and mastery when it comes to EPOS' risk management, from strategic, implementation, execution, and continuing review (with feedback loops into operations) perspectives.

5. Recommendations

ERIC EPOS has successfully achieved a remarkable milestone since its inception, the operational readiness which has been the goal of the implementation and pre-operational phases between 2019 and 2023. Nonetheless, the panel wishes to make the following recommendations which – if implemented – are expected to advance EPOS:

- **Scientific excellence and innovation**: The panel fully recognizes that EPOS is already making exceptional and unique contributions, that of setting up new thematic communities such as the Near Fault Observatories which create new communities out of more topical ones. But in order to fully realize the potential of EPOS in terms of scientific excellence and innovation, EPOS is encouraged to develop a strategy and implementation plan for value-adding services for end-users as is undertaken by the Integrated Core Services – Distributed (ICS-D). The panel also encourages EPOS to continue focusing on discovery and unlocking of "hidden" data not only in research institutions and laboratories but also in industry's data repositories. EPOS is also uniquely positioned to be eventually a repository that includes the long tail of data of the field (which includes for example derived data) even if data quality is not evident or if metadata quality is poor. Last, but not least EPOS is also strongly encouraged to continue its joint efforts to find financial resources to improve data FAIRness and quality.
- **User strategy and implementation**: the panel has identified the need for a well-thought through dissemination strategy and a sound implementation of the strategy to achieve a high level of awareness and knowledge of EPOS' capabilities in the Solid Earth science community towards achieving scientific excellence. While the panel recognizes that EPOS has already described such an approach in a recent response to a 2023 Horizon Europe infrastructure call, the panel believes this work is worthy in itself irrespective of the outcome of the call. EPOS is encouraged to continue emphasizing a user strategy where usage of the portal will be central. EPOS may explore ways to incentivize the use of the EPOS portal via prizes for early career researchers who use the portal. EPOS should spend considerable efforts on training courses for portal usage in and by all participating sub-communities and centers considering the very recent operationalization. In order to facilitate uptake of the portal, there is a need for a pre-defined role of EPOS when it comes to maintaining and reinforcing the implementation of data licensing within its comprehensive framework of intellectual property rights. Last but not least, the panel suggests the development and use of key performance indicators (KPI) that measure and quantify user uptake.

- **Socio-economic and technological impact**: despite the challenges of comprehensively measuring impact, the expert panel recommends the development and use of metrics to

measure the impact of EPOS. KPIs (key performance indicators) may address usage of the portal (e.g., the number of downloads once systems are fully established); measures of publications in various TCS but particularly those TCS that feature new communities; usage of EPOS among non-academic innovation communities (e.g., those in industry); and tracking research and innovation investments primarily in projects supported by the European Commission or other Europe-centric multilateral funding partnerships that use the EPOS research infrastructure.

- **Membership commitment**: to ensure the optimum value generation from the EPOS Thematic Core Services, the panel recommends to EPOS ERIC's members (1) to have the actual contributed membership fees of all member countries match the nominal membership fees; fees, which are the result of a carefully balanced application of subsidiary finance principles. (2) EPOS ERIC is strongly encouraged to continue in successfully responding to Horizon Europe calls dedicated to research infrastructures and to develop ways of featuring in call descriptions for research and innovation projects that explicitly address the use of research infrastructures (e.g., the Clean Energy Transition Partnership, other Horizon Europe partnerships, and other transnational and European funding instruments). (3) In the medium-to-long term, EPOS needs to continue to set as one of its strategic goals an increase of national resources which directly benefit EPOS for an ambitious growth agenda. Reaching this goal requires the successful and clear demonstration of added value for scientific research, technological development, socio-economic impact, and societal benefit. In particular, new significant scientific findings, visible to the public, based on the use of EPOS are an essential ingredient for funding organizations to increase financial appropriations to EPOS.

Appendix 1

Terms of Reference for the External Evaluation Panel of EPOS ERIC

omitted

Appendix 2

Documents consulted

omitted