ANNALS OF GEOPHYSICS, 65, 2, DM209, 2022; doi:10.4401/ag-8786
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Long-term sustainability of a distributed RI: the EPOS case

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Article history: received December 28, 2021; accepted April 2, 2022

Abstract

The European Plate Observing System (EPOS) is a distributed research infrastructure (RI) with the mission to establish and maintain sustainable and long-term access to solid Earth science data and services by integrating the diverse national research infrastructures under a common federated framework governed by EPOS ERIC (European Research Infrastructure Consortium). This paper presents the EPOS approach to ensure financial viability and to tackle the challenge of long-term sustainability of the RI during its operational phase. The EPOS approach to sustainable operation considers the scientific impact and the promotion of scientific research as the preconditions to achieve long-term sustainability. Enabling scientific excellence implies that high-quality data and services are provided reliably and continuously to establish the RI as the enabler of investigations to solid Earth scientists. The strategic approach and the solutions adopted by EPOS ERIC to address the long-term sustainability of a pan-European distributed RI are discussed in this paper focusing on the governance structure, considered as the qualifying dimension that gathers and connects the financial, legal and technical dimensions. The governance and the financial models are discussed to delineate the legal framework necessary to operate the EPOS RI relying on the implemented technical solutions. A sufficiently stable investment environment is necessary to allow the RI to concentrate on providing high quality services for their user communities. This paper discusses the current actions and challenges to be addressed for achieving this goal.

Keywords: Research Infrastructure; Sustainability; Solid Earth Science; Open Science; ERIC

1. Introduction

Research Infrastructures play a key role in the scientific research process through the generation of high-quality data and new technologies, often necessary to trigger innovation and scientific progress. Research Infrastructures (hereinafter RIs) are facilities, scientific equipment and observing systems (sets of instruments and networks) of a unique nature, identified by the scientific communities to conduct research and promote innovation in their fields [EU Regulation No. 1291, 2013]. RIs also include knowledge-based resources, i.e., collections, archives and repositories of scientific data, and e-infrastructures, i.e., data and computing systems and communication networks [ESFRI Roadmap, 2018]. Moreover, RIs bring together and attract large numbers of developers and users, fostering both domain-specific and cross-disciplinary investigations. In addition, RIs are identified as key enablers of socio-economic impact [OECD, 2019; van Belle et al., 2018]. For their implementation, different organizational models exist, typically single-sited RIs, such as large research plants in one single or a few fully dedicated sites (e.g., astronomical observatories, accelerator-based sources, nuclear reactors or extreme laser sources) or distributed RIs composed of geographically distributed observing systems and/or laboratories, remotely accessible computational resources and data repositories. RIs can offer their users physical access [see Philippin et al., 2019] and/or virtual access for remote usage of scientific data and related services [Petzold et al., 2019]. RIs are nowadays assuming an increasingly central role in supporting open science by fostering the sharing of scientific data and products. This is particularly relevant for environmental sciences [Kutsch et al., 2016; Sorvari et al., 2016; Petzold et al., 2019], but also for transdisciplinary initiatives like the European Open Science Cloud (https://eosc.eu). The key requirements for a useful and meaningful sharing of data are findability, accessibility, interoperability and reusability, which are combined in the so-called FAIR (Findable, Accessible, Interoperable, Reusable) principles (Wilkinson et al. 2016, 2018; Mons et al., 2017; Boeckhout et al., 2018). FAIR data management is currently an objective for RIs in Europe and a global challenge requiring well-defined principles and shared practices.

The role of RIs is evolving since the original stand-alone undertakings are more and more becoming part of a connected system forming a unique resource for advanced research and interdisciplinary analysis of complex scientific problems [ESFRI Roadmap, 2021]. For instance, national RIs are encouraged to network with international RIs, to deliver the best solutions to the national research communities [OECD, 2020]. The European Strategy Forum on Research Infrastructures (ESFRI) is coordinating the European landscape of RIs. ESFRI is a strategic body established in 2002 by the Council of the European Union to support a coherent and strategy-led approach to policy making on RIs in Europe. ESFRI periodically updates its Roadmap as mandated by the Competitiveness Council of the European Union to provide a coherent and strategic vision ensuring that Europe has excellent RIs in all fields of science and innovation. ESFRI has completed Roadmaps in 2006, 2008, 2010, 2016, 2018 and launched the last one in 2021 (https://www.esfri.eu). The ESFRI Roadmap contains a description of the European RIs and their progress status, based on a thorough evaluation and selection procedure. The Roadmap combines ESFRI Projects, which are new RIs in progress towards implementation, and ESFRI Landmarks, which are successfully implemented RIs. The ESFRI Roadmap also describes the broader landscape of research in Europe which is an important element of the ESFRI methodology [ESFRI, 2019].

ESFRI RIs apply a lifecycle approach coherent and consistent with RI funding under the EU Framework Programs for Research and Innovation. Moreover, the lifecycle of a RI is a reference to understand the needs and targets of the RI at a given time and at various stages [ESFRI Roadmap, 2021]. The lifecycle starts with the conception phase, which typically arises bottom-up from the scientific communities clustering around well identified scientific needs and goals and continues with the design-, preparatory- and implementation phases (see Figure 1). The preparatory phase is dedicated to the proof of the scientific concept and technical feasibility of the RI, including the architecture as well as the governance and financial models defining the organizational structure. Next, the implementation phase is dedicated to the development of the functional architecture and to the governance and management structure (Figure 1). For distributed RIs, the creation of a successful governance and financial structure may be of higher complexity than for single-sited RIs, requiring intense negotiations with national authorities and research organizations as both the *central hub* and the *national nodes* require specific and shared commitments to operate. The analysis of the potential user community, both science and innovation oriented, continues throughout the preparatory and the implementation phases.

In this paper, we present and discuss the concept development, design, preparation and implementation of the European Plate Observing System [EPOS, www.epos-eu.org, Cocco et al., 2022, this volume], a distributed RI dealing with solid Earth science in Europe, with the goal of discussing the approach adopted for long-term sus-

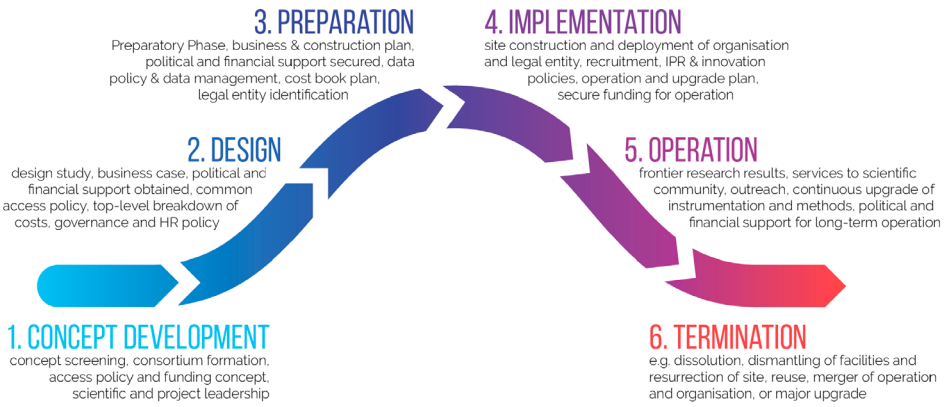

Figure 1. ESFRI lifecycle approach to RIs (ESFRI 2021) https://www.esfri.eu/sites/default/files/ESFRI_Roadmap2021_Public_Guide.pdf.

tainability. Solid Earth science brings together many diverse disciplines, such as geology, seismology, geodesy, volcanology and geomagnetism, as well as chemistry and physics as they all apply to the workings of the Earth. The EPOS mission is to establish and underpin sustainable and long-term access to solid Earth science data and services integrating diverse European Research Infrastructures under a common federated framework. To that end, EPOS grants open access to solid Earth science data through new e-science solutions to foster multidisciplinary scientific research in the diverse solid Earth disciplines. In addition, EPOS promotes physical access to research facilities in solid Earth science across Europe. EPOS entered the ESFRI Roadmap in 2008 and became a landmark in 2018. The European Commission granted EPOS the ERIC status in 2018 Cocco et al., 2022, this volume]. Figure 2 shows the current lifecycle status of the EPOS RI and illustrates the different stages successfully achieved on its way to sustainable operations. Indeed, the long path towards the construction of the EPOS RI explains the "long-term" vision anticipated in the EPOS mission statement. Currently, the so-called Pilot Operational Phase (EPOS POP, 2020-2022) is aimed at testing altogether the different frameworks (governance, legal, technical, financial) developed so far to ensure access to the interoperable EPOS central hub (ICS-C). Legal in this context also includes the regulatory framework specifically developed for the implementation of EPOS. Another key objective of the POP is to bring EPOS from financial viability to long-term sustainability, a common challenge for infrastructures transitioning from the establishment/construction stage into operations (OECD, 2017). The construction stage should be more explicitly identified in the ESFRI lifecycle model (Figure 1), since it is a necessary and costly step to move forward the RI operation. The latter objective is also addressed through the EPOS SP project (EPOS Sustainability Phase), funded by the European Commission within the Horizon 2020 Framework Program (H2020-INFRADEV-2019-2 call, project n° 871121), since sustainability is the overarching goal of the EPOS POP.

Figure 2. EPOS timeline during the RI lifecycle and current stage EPOS Pilot Operational Phase (POP)

The issue of long-term sustainability of RIs is addressed in this paper by discussing the EPOS federated approach to integrating scientific data and fostering FAIR data management in solid Earth science [Cocco et al., 2019; Bailo et al., 2020; 2022, this volume]. As already introduced, RIs are long-term enterprises requiring decades to progress from the conception and design to the implementation and construction phases and designed to remain operational for several decades or more [see for instance ELIXIR, 2019]. Moreover, RIs represent strategic investments which are indispensable for enabling and developing research in all scientific domains and require careful planning as well as continuous support, not limited to financial aspects, to maximise their socio-economic impact [Van Belle et al., 2018; ELIXIR, 2019]. Developing and maintaining the sustainability of a pan-European distributed RI like EPOS is a complex endeavour, which has to be considered a target during the entire RI lifecycle. Indeed, the de-centralised nature of EPOS is also reflected in its approach to sustainability, as specific elements, not present in single-sited infrastructures, need to be considered [OECD, 2014]. In the following, we present the approach developed to ensure the long-term operation of EPOS, in full awareness of the important strategic investments made in the past and with the ambition to make EPOS resilient to the rapidly evolving financial and political contexts.

2. The EPOS architecture

Since its conception phase, EPOS is managing its complexity relying on a shared and effective roadmap towards operations in which the scientific concept and the architecture are evolving consistently with the original EPOS vision and mission and with the ambition to ensure sustainability.

Figure 3 depicts the EPOS functional architecture, characterised by an EPOS ERIC perimeter and a Delivery Framework perimeter. The EPOS ERIC perimeter contains the components managed under the EPOS ERIC governance as assets of the RI (ECO, ICS-C, further explained in the following). The EPOS Delivery Framework perimeter contains other essential components for the delivery of the EPOS mission (TCS, ICS-D, also further explained in this section), whose governance is shared with the participating research communities.

There are three distinctive elements in the EPOS functional architecture (see Figure 3): data generation; qualification and quality-management; integration and provision. Each element can be seen as a distinctive layer. The first element, data generation, is represented by the National Research Infrastructures (NRIs) characterising the framework in which data are generated from multiple locations, processed, analysed and archived. This includes scientific data like measurements from different observing systems and sensors, but also information about laboratories or observatories accessible to researchers for physical access [see Wessels et al., 2022, this volume]. The second element, data qualification and quality management, is represented by the Thematic Core Services (TCS), established in EPOS since the implementation phase (2015-2019) to ensure an effective and suitable management of the available high-quality data over the entire data lifecycle for a given domain (e.g., seismology). The TCS[1] represent the community-specific integration and the governance framework to ensure the data and service provision within EPOS. The third element, integration and provision, is represented by the ICS (Integrated Core Services), which is the platform where data and services are integrated and made interoperable, providing user access through the novel EPOS data portal[2] [Bailo et al. 2022, this volume]. The ICS is composed of the ICS Central Hub (ICS-C) and the ICS Distributed (ICS-D). The latter represents the virtual research environment, where access is provided to services for the analysis of aggregated datasets and for developing computational Earth science.

The EPOS ERIC legal seat is hosted in Italy (INGV Rome), where the Executive Director, supported by the Executive Coordination Office (ECO), ensures the governance of the EPOS RI and the coordination of the EPOS Delivery Framework. The ICS Central Hub (ICS-C) is hosted in France (BRGM) and the United Kingdom (UKRI-BGS). The ECO and the ICS-C interact through the ICS-C office, composed of members of EPOS ERIC and of the ICS-C hosting organisations. The ICS-C office is led by the ICS-C director who reports to the EPOS ERIC Executive Director.

The rationale behind this architecture is to guarantee an effective engagement of the research communities providing the required skills for the data and service provision. At the same time, it ensures the coherency with and the effectiveness of EPOS's legal, governance and technical framework [see Cocco et al, 2022, this volume for a detailed description of the EPOS Delivery Framework].

1 https://www.epos-eu.org/tcs

2 https://www.epos-eu.org/integrated-core-services, https://www.epos-eu.org/dataportal

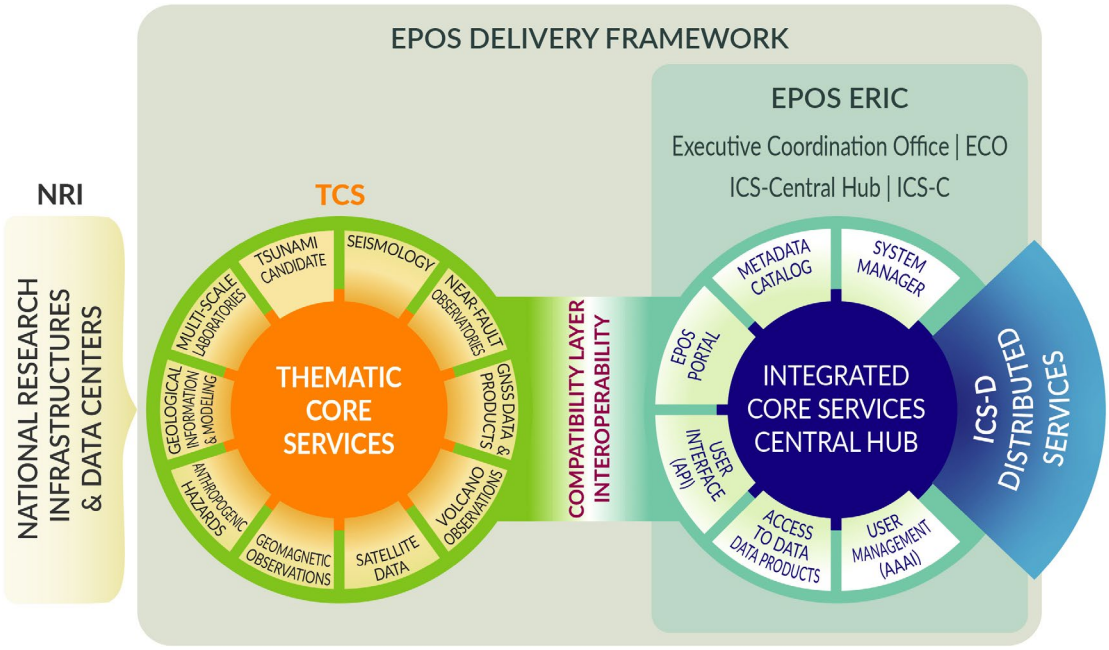

Figure 3. Main components of the EPOS Architecture: NRIs, TCS and ICS (ICS-C & ICS-D) form the EPOS functional architecture, coordinated by EPOS ERIC, and designed to ensure the EPOS data and service provision. The Integrated Core Services Central Hub (ICS-C) and the Executive Coordination Office (ECO) belong to the EPOS ERIC legal subject.

3. The EPOS science case

The main mission of RIs is to serve and facilitate scientific research. According to ESFRI, landmarks have been presented as "*pan-European hubs of scientific excellence, generating new ideas and pushing the boundaries of science and technology*" and "*important pillars of European research and innovation for the next decade*" (ESFRI Roadmap, 2016). Scientific excellence has been included by ESFRI as one of the main recommendations for tackling the challenge of long-term sustainability of RIs [ESFRI Scripta, 2017]. Therefore, impact on science can be considered as the prerequisite and main driver for RI sustainability. For a distributed RI such as EPOS, enabling excellence in scientific research implies that high-quality data and services are provided reliably and continuously to establish the RI as the enabler of investigations to solid Earth scientists. This also requires the effective engagement of the user community, as well as access mechanisms for researchers to use the RI when addressing the most challenging problems in solid Earth science. For these reasons, the EPOS approach to long-term sustainability considers the science case as the essential requirement motivating the establishment of the RI, confirming its original vision and mission statements. There are specific reasons why in EPOS we refer to scientific impact and perspectives rather than scientific excellence, as will be discussed in this paper.

The EPOS science case is fundamentally represented by the multidisciplinary contents of its Delivery Framework. Data and services provided by EPOS can contribute effectively to answering grand challenges and big scientific questions as well as to maintain Earth a safe, prosperous, and habitable planet. For instance, accessible data can be used to forecast volcanic ash emission and related hazards by bringing together observations from volcanology, petrology, rock physics and geochemistry, meteorology and atmospheric sciences. EPOS can also promote multidisciplinary investigations of anthropogenic deformation for a safe and secure exploitation of geo-resources. Seismological data and observations can be used for calibrating ground motion prediction equations (i.e., measuring the ground shaking during earthquakes and its distribution in space) for seismic hazard assessment and risk mitigation. The growing ability of scientists to make accurate predictions about natural phenomena and to improve our understanding of how planet Earth works can be strengthened by facilitating access to multidisciplinary solid Earth data enabling re-use and serendipity. This of course requires the access to high quality data and products in a way in which they can be analysed, processed and modelled to derive new products for science and innovation. This can be done through the EPOS ICS (see Figure 4). This is, indeed, the EPOS goal and the long-term scientific perspective.

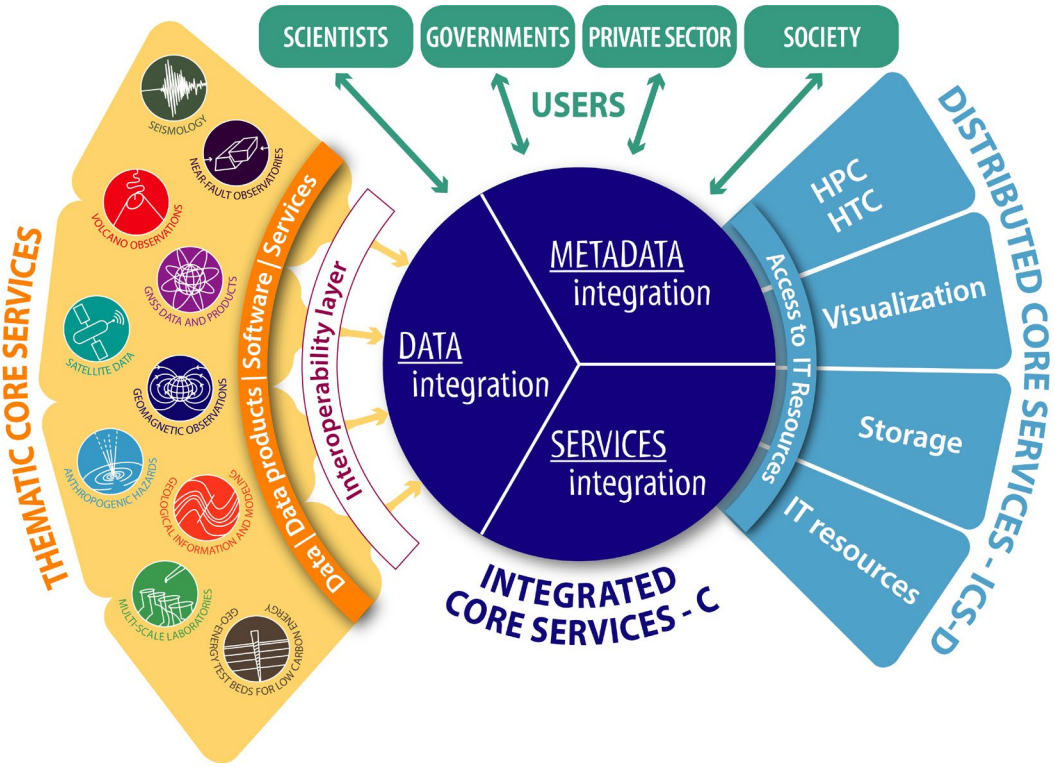

Figure 4. The TCS-ICS System representing the EPOS Delivery Framework.

By enabling scientists to access and use its data portal, EPOS can promote the discovery of the excellent opportunities for Earth science. The EPOS Delivery Framework foresees continuous developments deriving from the promotion of the use of the available data and services also associated with the generation of new scientific products that can be shared and made accessible by EPOS after quality-control and standardization. This corresponds to transforming users into data product providers, fostering open science and the culture of data sharing. The community building achieved by EPOS and the enhanced integrated contributions to society that will be available by using EPOS services, further corroborate the EPOS impact on science and its added value for society.

A shared scientific perspective and a proved scientific impact represents the framework in which sustainability can be addressed in the long term. In the following section we will discuss the EPOS approach to sustainability, intended as the sustainable operation of a science-oriented distributed RI.

4. A multidimensional approach to sustainability

The EPOS RI successfully concluded its implementation phase in 2019 and is currently facing the transition to the operational phase. This transition represents a specific stage in the lifecycle of EPOS, named EPOS Pilot Operational Phase (EPOS POP), and it is governed by a Strategic Plan (2020-2022) with the overarching objective of building and operating the EPOS Delivery Framework (Figures 2 and 3) in a sustainable way. The EPOS SP activity plan represents a specific objective of the current EPOS ERIC Strategic Plan, dealing with the financial viability and tackling the challenge of long-term sustainability.

The first strategic action has been performing a so-called *landscape analysis* of the EPOS Delivery Framework. The landscape analysis has been designed to contribute to the implementation and the adoption by EPOS ERIC of the Long-term Sustainability Plan under development. Specifically, the landscape analysis consists of the detailed mapping of the components included in the EPOS Delivery Framework, e.g. ICS, TCS. We consider that each component shapes the construction and operation of the RI, thus affecting the overall sustainability of EPOS. By analysing each component through qualifying features or *dimensions*, we are able to create awareness about the sustainable operation of the EPOS RI and its Delivery Framework. Extending the landscape analysis to the external framework is presently envisioned as a subsequent step to move forward in the path to sustainable operation.

In addition to the scientific framework already discussed, the following dimensions can be considered as key for ensuring sustainable operation:

I. Governance dimension
II. Financial dimension
III. Legal dimension
IV. Technical dimension
V. Users' environment
VI. Other stakeholders' environment (private sector, society)
VII. Global connections.

Indeed, the last three dimensions contribute to the exploitation of the RI, thus essentially affecting the scientific perspectives discussed in the previous section. The inclusion of the users' and stakeholders' dimensions within the landscape analysis is motivated by the fact that they can influence and be influenced by the way in which we are building and operating the EPOS Delivery Framework. It is also within these two dimensions that communication is tackled as an essential aspect for the exploitation of the RI. As an example, EPOS ERIC has a dedicated vocabulary task force dedicated to harmonise and improve the vocabularies present in the future EPOS data portal.

In addition, the EPOS approach to sustainability relies on the definition and the implementation of suitable models for the governance and financial dimensions as well as of effective and coherent legal and technical solutions. These models have been designed and implemented during the previous and current stages of the RI lifecycle. The governance dimension of the EPOS sustainability depends on the effectiveness of the adopted governance model. The EPOS governance model has been designed in full awareness that a distributed research infrastructure must rely on key components that are under the control of the ERIC. The model has been implemented in order to enable the EPOS ERIC management and coordination, relying on authoritativeness and trust, as well as to federate data and service providers with EPOS ERIC and ICS-C, through TCS community coordination. To this task, the implemented governance structure considers the Executive Coordination Office (ECO) and the ICS Central hub (ICS-C) as the components under the governance of EPOS ERIC. This is graphically represented by their inclusion in the EPOS ERIC perimeter (see Figure 3). The TCS are located outside the EPOS ERIC perimeter, but within the perimeter of the EPOS Delivery Framework (see Figure 3). This is because the TCS have their own governance structure operated by the involved research organizations and scientific communities. This translates the concept of a federated approach into a governance model suitable for the coordination of the EPOS Delivery Framework by the ERIC.

The building of the adopted governance structure requires appropriate financial and legal frameworks. They have been implemented through dedicated solutions, such as host premium provision by ERIC members (hosting countries) aimed at financially supporting the operation of the components located inside the EPOS ERIC perimeter as well as the signature of Consortium Agreements by research organizations to join and support the TCS. These solutions will be discussed in the next section. Here, we anticipate that the legal framework has been implemented to define: (i) the contents of the Partnership Agreements between EPOS ERIC and ICS-C hosting organisations necessary to host the ICS-C in countries different from that of the ERIC legal seat; (ii) TCS Consortium Agreements between research organisations recognizing roles and commitments to implement the TCS (including data policy, access rules, service provision, supply letters for data provision); (iii) Collaboration Agreements between research organisations and EPOS ERIC to federate TCS, sharing resources to support sustainable governance as well as data and service provision, as well as (iv) other legal agreements to support training and the community's scientific and outreach initiatives.

The financial framework has been implemented according to the RI architecture (see Figures 3 and 4) and to the governance structure. The EPOS financial model is illustrated in Figure 5. This figure shows the four founding components of the EPOS architecture, namely the National RIs (NRI), the ECO, the ICS and TCS and the three envisioned funding sources. These are i) national funding in the form of EPOS ERIC membership fees in cash (ERIC fees in Figure 5), ii) national funding provided as host contributions (ECO, ICS) or in-kind contributions (TCS) to EPOS ERIC, as well as directly to research organisations for the operation and development of TCS and/or for data generation and maintenance of national research infrastructure (all labelled under Direct funding in Figure 5), and iii) EU funds for activities devoted to further development and integration. The rationale behind this financial model is twofold: on the one hand, including in the EPOS ERIC budget cash contributions, host contributions and in-kind contributions (IKC) for supporting operational costs and, on the other hand, using European and distinct national funds for development and for the sustainability of the NRIs. The financial model also relies on the imple-

mentation of a TCS Cost Book to manage the sustainability of TCS and the data and service provision, by quantifying the resources provided in-kind by national and international research organizations. Although TCS are outside the EPOS ERIC perimeter, the financial model contemplates cash contributions to TCS for the establishment of collaboration agreements with EPOS ERIC for TCS governance and coordination, training and outreach, virtual access to data and service provision and physical access to research facilities. These are small contributions compared to the resources required at national level and are aimed at leveraging national support to TCS sustainability.

The estimated costs of the EPOS Delivery Framework are nearly 15% of the total operational costs spent by national governments to operate the national RIs federated in EPOS. This might represent a feasible starting condition to address financial viability. To take full advantage of the major investments in national RIs, the data they produce need to be made openly and easily available to researchers across a broad span of fields in sustainable environments. This introduces the technical dimension of the sustainable EPOS operation.

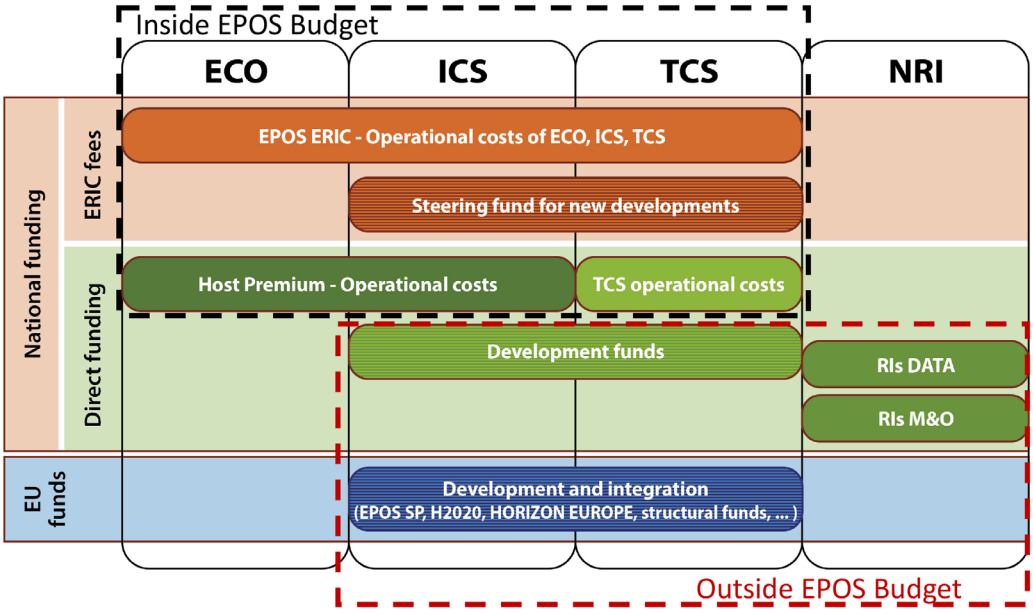

Figure 5. The EPOS Financial Model. Dashed boxes show the elements and the funding sources included inside (black) and kept outside (red) the EPOS ERIC Budget.

The technical framework is represented by the implementation of the EPOS functional architecture (Figure 3), which has been designed to respond to the increasing amounts of data generated by solid Earth national RIs. This requires harmonizing and integrating the standardized data and metadata provided by the communities through service providers belonging to TCS, ensuring interoperability with the ICS-C, as well as to operate the EPOS data portal ensuring integrated access and findability to users and stakeholders. The technical dimension of sustainable operation of the whole EPOS Delivery Framework has direct implications with the user engagement and stakeholder framework.

The governance, legal, technical and financial dimensions identified to characterize the sustainability concept are interdependent, as evidenced by the previous discussion. However, we consider the governance dimension as the qualifying dimension that connects the other three dimensions, establishing the EPOS sustainability framework. In the next section, we will further discuss the EPOS approach to sustainable operations with the goal of presenting adopted solutions and challenges to address the long-term sustainability of the EPOS RI.

5. Solutions and challenges

EPOS ERIC has been designed to govern and operate a pan-European distributed RI. The EPOS governance structure relies on the shared decision, taken during the preparatory phase, to set up an ERIC in order to establish and operate the research infrastructure. This choice has characterized the preparatory and implementation

phases influencing the governance and financial models. The EPOS governance model is illustrated in Figure 6. The General Assembly is the EPOS ERIC decision-making body, and it is composed of representatives from national authorities of the countries having joined the ERIC. Fourteen out of the 25 countries involved in EPOS have joined EPOS ERIC so far.

According to the ERIC Regulation [EU Regulation No. 723/2009], the Statutes of an ERIC shall contain the rights and obligations of the members, *including the obligation to make contributions to a balanced budget*. In the EPOS ERIC Statutes [2018], members and permanent observers, directly or through representing entities, shall provide annual membership fees in cash, host contributions (if applicable), and may also provide other contributions in kind.

The ERIC members providing host contributions are identified as Hosting Countries. According to the EPOS architecture (Figure 3) and the Governance and Financial models (Figures 5 and 6), host contributions are foreseen for hosting and operating the two core components of EPOS ERIC, namely the ECO and the ICS-C. Italy is the host country for hosting the ECO and the legal seat. France and United Kingdom are the two hosting countries for hosting and operating the ICS-C. It is therefore evident that the host contributions play a key role in the EPOS ERIC governance and financial models (as shown in Figure 5).

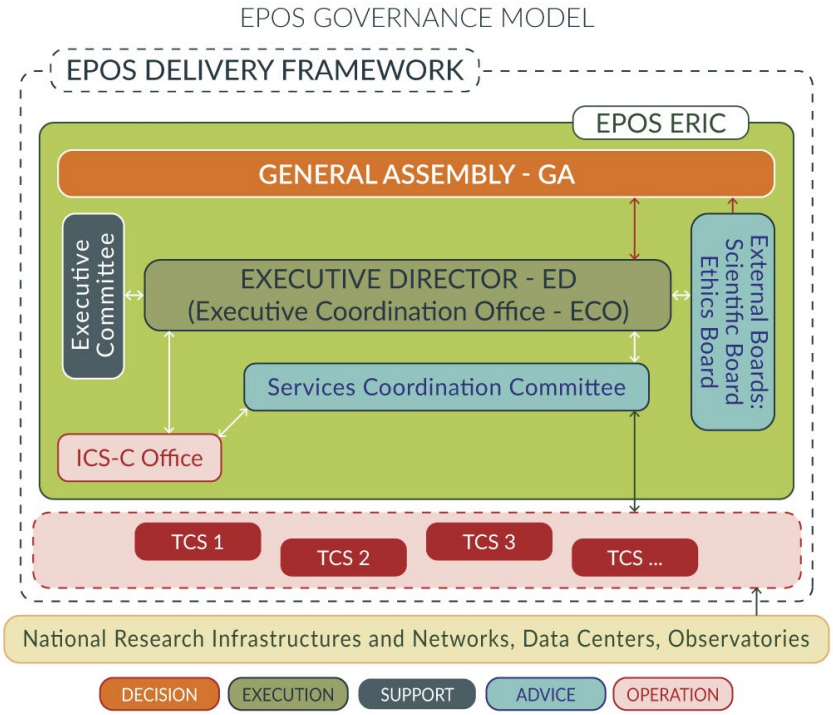

Figure 6. Details of the EPOS governance structure (arrows representing governance relationships): the General Assembly is composed of representatives from national authorities of those countries that joined the ERIC is the decision body of EPOS ERIC; the Executive Director (ED) and the ECO oversee the managing of the ERIC as execution subjects. The Service Coordination Committee is composed of representatives from the TCS, ICS and the ECO and it is chaired by the ED. The Executive Committee is composed of the chair of the SCC, the scientific, community building and IT officers (the latter chairs the IT board) and the ICS-C Director. EC is chaired by the ED. The ICS-C office is composed of staff members coordinating the operation of the ICS Central Hub. A TCS board is established in each TCS to coordinate the community and govern the data and service provision.

The host contribution solution is common to several other distributed RIs, being considered an effective way to share resources for operating core components of the ERIC coherently with the governance structure. Its implementation relies on direct funding from ERIC members, which is straightforward when the financial contribution is provided as cash. In this case, the contribution is part of the EPOS ERIC budget, and as such reported in the financial books of the ERIC. If the host contribution is provided by a research organization on behalf of the ERIC member, a mandate letter is necessary to delegate the research organization and include the financial contribution in the ERIC

budget, confirming the commitment taken by the ERIC member in the General Assembly (GA). The necessity of the mandate letter has been thoroughly discussed among ERIC members in the GA. It may pose a challenge, in that it may trigger decisions at national level taking time to be implemented, yet they are important to reinforce the political commitment to hosting a key component and to fully implement the adopted governance structure. This situation might be common to other distributed RIs. A further challenge is the inclusion of in-kind contributions (IKC) in the EPOS ERIC financial books, especially when the IKC refer to already existing e-infrastructures or facilities and not fully dedicated to the exclusive use of the ERIC. To address this challenge in EPOS, we have distinguished the host contributions associated with resources dedicated to host and operate the core components located *inside* the EPOS ERIC perimeter, from in-kind contributions dedicated to support activities for key components located *outside* the ERIC perimeter but within the EPOS Delivery Framework perimeter (see Figure 3 and 6). The EPOS ERIC perimeter identifies the assets to be kept under ERIC governance (the ECO and the ICS-C); consequently, they are part of the EPOS ERIC budget and are reported in the financial books. This is also needed to ensure that efforts and investments can be sustained over long periods to develop the next-generation technology that provides a competitive edge and can help driving innovation. The EPOS Delivery Framework perimeter contains the TCS in charge of key actions such as TCS governance and coordination, data and service provision, outreach and community building. The Consortium Agreements have been implemented to engage national and international research organizations in TCS activities, including the data and service provision. The creation of TCS Consortia was a key component in stabilising the EPOS Delivery Framework because they ensure accountability, representativeness and transparency with all the involved organisations and their personnel and give a clear mandate to the TCS coordinator to interact with EPOS ERIC. The pan-European dimension of the EPOS federated Delivery Framework is corroborated by the number of countries and research organizations participating to the data and service provision and to the TCS governance: 25 countries are involved in EPOS through nearly 140 research organizations. Among them, 65 research organizations and 4 international organizations are formally engaged in the TCS consortia, belonging to 21 countries (out of the 25 involved in EPOS). The data and service provision are currently ensured by 35 Service Providers, which make available nearly 197 validated data, data-products, and services provided through 236 web-services.

An important challenge for EPOS is to harmonize the pan-European integration with national strategies as well as to keep the national research organizations committed to sharing resources for the operation of the EPOS Delivery Framework [Atakan et al., 2022, this volume]. Most of the national research infrastructures engaged in EPOS are deployed for the monitoring of areas prone to geo-hazards and the surveillance of national territory including areas used for exploiting geo-resources. They have not been deployed for the specific EPOS mission. EPOS is integrating the data, scientific products and services generated by these national RIs to create new services for the integrated use of multidisciplinary aggregated sets of data. For this reason, a portion of the total costs for the TCS operation (inventoried in the TCS Cost Book) is ensured by the national research organizations committed to maintaining the operation of their RIs. This is considered as in-kind resources, a background information in the TCS Cost Book, not reported in the EPOS ERIC budget and annual activity plan, as these resources are external to EPOS ERIC. At the same time, EPOS ERIC is committed to ensuring the financial viability and the sustainable operation of the EPOS Delivery Framework. To this task, EPOS is encouraging the provision of national funds for support of the participation to TCS and their data and service provision, as envisioned in the financial model shown in Figure 5. These funds are considered as in-kind contributions (IKC) in the TCS Cost Book. Indeed, EPOS ERIC strives to improve the TCS sustainability through increased IKC. For example, by financially contributing to the TCS governance and coordination, EPOS ERIC promotes the active search of mechanisms to strengthen sustainability, as this is an activity included in the collaboration agreements with EPOS ERIC. At TCS level, this mechanism favours the sharing of approaches across different research organisations. Also, EPOS ERIC disseminates the model of EPOS national consortia put in place in several countries for more efficient interactions with ministries and sponsoring or funding agencies.

Within the EPOS SP project, we are exploring the suitability of this approach to ensure financial viability, provided that the IKC are recognized by both the committed research organizations and the EPOS ERIC General Assembly. Under these conditions, these IKC can be annotated in the ERIC financial books and included in the sustainability plan. The ongoing landscape analysis mentioned above represents a direct contribution to the monitoring of financial viability as well as a tool to assess values and gaps in operating the EPOS RI.

The sustainable operation of the EPOS Delivery Framework also requires the implementation of a suitable legal framework. A set of different legal agreements have been implemented in order to establish appropriate and effective connections with research organizations depending on their role, responsibility and commitments. Partnership agreements have been implemented to recognize the governance, financial and technical frameworks

established to host the core components located inside the EPOS ERIC perimeter. In this case, research organizations signing the Partnership agreements with EPOS ERIC are recognized as hosting organizations and representing entities in the EPOS ERIC Statutes. This legal agreement regulates the hosting and the operation of assets belonging to EPOS ERIC and included in its budget and financial books. Multi-year Collaboration Agreements have been set up to share resources between EPOS ERIC and the research organizations committed to coordinating the TCS, as well as with those acting as service providers. TCS coordinators and service providers are identified in the Consortium Agreements signed to establish the TCS. Collaboration Agreements also ensure the IT development and the TCS-ICS interactions and can support sponsored research activities. Preliminary results emerging from the landscape analysis indicate that EPOS ERIC will sign a high number of legal agreements to coordinate and operate the EPOS Delivery Framework. This is an important aspect of the sustainability dealing with the legal dimension that needs to be analysed in order to adapt suitable practices and transform viability into long-term sustainability.

The legal dimension of sustainability also concerns the data and service provision and requires the adoption of practices to sustain access and use of data and scientific products. EPOS integrates data from different data providers through shared policies and access rules, which requires the provision of supply letters from data providers to service providers to enable data redistribution on their behalf. There is a legal framework to be built in order to make the EPOS federated approach to data and service integration operational, coherently with the governance and financial models and with the technical developments. In other words, the generation and exploitation of digital data, products (including software) and services require a suitable legal framework. This challenge is common to all RIs, e-infrastructures and data infrastructures designed to contribute to open science through the management and the sharing of FAIR data. The legal framework is also affecting the technical dimension, since effective policies are required both for redistributing data and/or scientific products and managing users' information to access the EPOS data portal (i.e., GDPR, authentication, authorization).

The technical dimension of sustainability concerns the operation of the TCS-ICS system, the key component of the EPOS Delivery Framework enabling data and service provision. In accordance with the functional architecture and the governance structure, TCS-ICS interaction is considered a permanent activity in EPOS, necessary to ensure both operation and IT development. For this reason, this strategic action is coordinated by the University of Bergen (Norway) and associated activities are included in the EPOS activity plan. This exemplifies the need for distributed RIs to adopt an organizational structure functional to the governance and technical operation and capable to engage partners and share responsibilities. The maintenance of the data and service provision also requires automated procedures to implement data and metadata for ensuring interoperability and FAIR data management. This is a further essential element for the sustainable operation of the EPOS RI. To ensure the provision of high-quality data and services reliably and continuously through decades requires human resources and skills. The long-term sustainable operation of the EPOS distributed RI involves continuous interactions among service providers, TCS communities and ICS-C operators, that have to be managed to ensure adequate performance, engage users and follow the users' and stakeholders' expectations. This challenge is motivating the current stage of EPOS, namely the Pilot Operational Phase, and corroborating the need of testing and implementing the interface between TCS and ICS from a technical, governance and legal point of view. To tackle this challenge, dedicated surveys have been envisioned in the activity plan of the EPOS SP project in order to interact with data and service providers. This strategic action is currently on-going and will be further discussed in the next section.

6. Discussion

The number of countries (25) and research organizations (≈140) participating in the EPOS integration plan corroborates its pan-European dimension. This is surely a good starting point and represents an added value for finding solutions to share resources and strengthen EPOS sustainability. However, this requires the adoption of an effective governance and a suitable approach to harmonizing national strategies and priorities with the EPOS needs and requirements [see Atakan et al, 2022, this volume]. The recognition of the EPOS role by the national authorities (ERIC Members or Observers) and the confirmation of their commitments, not limited to financial contributions to EPOS ERIC are essential to tackle the challenge of ensuring long-term sustainability [see also Cocco et al. 2022, this volume]. In this framework, the current EPOS challenge is to ensure the financial viability of the EPOS operational phase, also relying on national funds to support data and service provision, as well as to create the conditions for addressing long-term sustainability.

According to ESFRI, a robust long-term vision is essential to successfully develop, construct and operate Research Infrastructures [ESFRI Roadmap, 2018]. The EPOS RI has been conceived with a long-term vision to develop and operate its Delivery Framework. ESFRI set up an ad hoc Working Group (WG) in 2016 with the mandate to provide a set of recommendations to strengthen the Long-Term Sustainability of RIs contributing to the dedicated action plan of the European Commission. The Working Group delivered an exhaustive report going well beyond the mere economic analysis [ESFRI Scripta, 2017]. The report proposed seven main recommendations covering the key aspects of long-term sustainability of Research Infrastructures. These recommendations were expanded into 35 specific points ranging over securing highly qualified and motivated human resources, realizing a robust transfer of information to society from the Research Infrastructure via a quality-controlled e-infrastructure, building an effective interface between RIs and innovation activities, understanding the actual value of the diverse benefits to society, addressing the optimal governance and management structure and promoting coordination among RIs [ESFRI Scripta, 2017]. EPOS has developed its approach to long-term sustainability trying to adopt practices capable to address these recommendations coherently with its scientific mission.

According to the ESFRI Report, scientific excellence is the necessary condition for sustainability throughout the entire RI lifecycle and its persistence is crucial in the long-term operational phase. Excellence in science and outstanding quality services to the users are imperative for the successful performance of each RI, and they are addressed in the monitoring and reviewing processes by ESFRI. This justifies the EPOS decision to consider the scientific impact and perspectives as the overarching framework to drive the sustainable operation of the RI during the entire lifecycle through the definition of suitable practices for each of the main qualifying dimensions of sustainability (i.e., governance, financial, technical and legal dimensions). As anticipated before, in EPOS it has been intentionally decided to ensure and assess the scientific impact resulting from using the data and the services made available to users, rather than focusing on establishing excellence. In other words, EPOS has acknowledged the ESFRI's indication to establish and maintain excellence but adapted it to its vision and mission. EPOS is a science-driven RI dedicated to unlocking the innovation potential of exploiting multidisciplinary data and services generated by the involved thematic communities (TCS) in solid Earth science. The EPOS functional architecture, relying on the TCS-ICS system, has been designed to fully exploit the RI's potential to enable scientific research, promoting innovation in all scientific domains while fostering cross-disciplinary investigations in Earth science. This is the scientific perspective, and the EPOS scientific impact will be monitored to preserve the long-term exploitation of data and services by scientists and other stakeholders.

The EPOS access rules and data policy have been designed and implemented to be coherent with open access and FAIR data management. This implies that user access mode to the EPOS platform (i.e., the TCS-ICS system and the EPOS data portal) is open and not limited to users from those countries participating to EPOS ERIC. This has implications on the expectation to establish scientific excellence. The European Commission in 2016 published a document concerning principles and guidelines for access to RIs and related services [European Charter for Access to Research Infrastructures, 2016]. They considered three access modes for RIs: excellence-driven access, market-driven access and wide access. The excellence-driven access allows users to get access to the best facilities, resources and services wherever located after peer review evaluation conducted by internal or external experts. The market-driven access mode applies when access is defined through an agreement between the user and the RI, involving the payment of a fee for the access, that may remain confidential. The wide access mode guarantees the broadest possible access to scientific data and services provided by the RI to users wherever they are based. EPOS RI has adopted the latter mode in order to maximise findability, accessibility and re-use of the provided data and services. EPOS excluded peer-review and pricing of the data because its federated approach to integrating data and services relies on joint efforts to share data which are not owned by EPOS ERIC. This has implications on the sustainable operation and on the future EPOS ERIC long-term sustainability plan. Because this situation is common to several other RIs in environmental science, it would have been reasonable to expect that the access mode adopted by these RIs would have greater visibility and consideration by the European Commission, rather than to be included in the generic wide access mode.

As explained before, EPOS is currently testing the TCS-ICS system and the capacity to maintain the data and service provision operational. These tasks are characterizing the EPOS Pilot Operational Phase [EPOS POP, 2020-2022] together with the implementation of a sustainability plan. The latter is the overarching objective of the EPOS SP project. The successful completion of the EPOS POP is essential to demonstrate that the EPOS RI works and is capable to enter in its fully operational phase. This is an extremely important message to be delivered in 2022 to the national authorities and EPOS funders. To this goal, the landscape analysis of the EPOS Delivery

Framework is a crucial element to adopt suitable metrics for analysing the qualifying dimensions identified in EPOS to define sustainability. This requires the assessment of the effective governance, supported by a suitable legal framework, as well as the appropriate management of the EPOS RI. Following the ESFRI WG indications, the sustainable operation of an RI requires a human resources plan ensuring skills and experiences to have the right people at the right place and at the right time. This does not solely concern the staff members of the EPOS ERIC Executive Coordination Office (ECO), but also the ICS-C and the TCS implying an effective TCS governance and harmonization between EPOS ERIC needs and contributions by participating research organizations. The long-term sustainable operation of the EPOS distributed RI, through its federated approach to data and service integration and provision, requires an effective plan to engage human resources and skills to be included through time in the governance and organizational structures. This challenge is common to both EPOS ERIC and the TCS, as well as more generally to other ERICs as highlighted by the EGERIC expert group (2021).

As soon as EPOS will start its operational phase in 2023, the assessment of the exploitation of data and services by users and stakeholders will be an important factor to corroborate its impact and to confirm the appropriateness of previous investments. This will be an important verification of the technical dimension of EPOS. In parallel with the evaluation of the exploitation of the EPOS data and services, the assessment of the EPOS impact in general, and the scientific impact in particular, will be conducted with appropriate key performance indicators and qualitative impact indicators. They have already been identified and the adopted metrics is currently under discussion. This includes independent evaluation ensured by the EPOS ERIC Scientific Advisory Board and by the Ethics Board, created to impartially advise the ERIC General Assembly on scientific and ethics-related topics. Following the recommendations of the ESFRI WG, demonstrating the economic value and the wider benefit to society is vital for RIs. This implies that sufficient resources have to be dedicated both to evaluating the EPOS value to the economy and society at large and to communicate this to targeted audiences, from the national authorities to policy makers and research organizations, in order to confirm their commitments toward the long-term sustainable operation of the EPOS RI [Marti et al., 2022, this volume].

The abovementioned actions are strategic to discuss the long-term funding with national authorities and research organizations, while communicating EPOS's achievements in fostering multi-disciplinary and cross-disciplinary research addressing the societal challenges related to geohazard and to the sustainable exploitation of geo-resources. EPOS has currently ensured the financial viability of the EPOS POP. The financial viability and the long-term sustainability of the EPOS Delivery Framework require further resources and the increase of the financial contributions by ERIC Members in terms of both membership fees and in-kind contributions, as well as through the engagement of new ERIC Members. Long-term sustainability will also depend on national investments in RIs and, in particular, in national funds dedicated to support service providers (national nodes) and data providers. This further national funding will be likely represented by direct support to national nodes, reported in the TCS Cost Book and in the EPOS ERIC Financial Books as in-kind contributions. To achieve this goal, the coordination with national authorities and national research organizations has been implemented in the EPOS SP project to develop and maintain a dialogue with EPOS contributors and funders. This will be a delicate and vital stage of the consolidation of EPOS sustainability, which requires effective communication with all potential stakeholders (ERIC members, other national authorities, research organizations) to explain demand and impact and this needs the adoption of efficient communication strategies.

7. Conclusions

EPOS is a distributed RI with the mission to establish a sustainable access to solid Earth science data and services, integrating national research infrastructures under a common federated framework governed by EPOS ERIC. To accomplish its mission, EPOS has been implemented to ensure scientific impact and innovation, enabling access and use of multidisciplinary data and products in solid Earth science. For this reason, scientific impact and novel perspectives emerging from using the provided data and scientific products is considered in EPOS as the overarching frame to undertake a sustainable operation of the RI. In other words, this is the context in which enabling scientific excellence through the governance of a stable and effective exploitation of the RI while addressing long-term sustainability.

The European Plate Observing System (EPOS) has successfully completed its implementation phase and it is currently facing the transition to its fully operational phase. This transition is not sharp and immediate; rather it

requires time and a dedicated stage in the EPOS lifecycle aimed to construct and further develop the RI together with the testing of the operational performances. This stage is represented by the currently ongoing EPOS Pilot Operational Phase, which is dedicated to consolidating the EPOS Delivery Framework (from governance, legal, financial and technical points of view), testing the TCS-ICS system, and addressing the sustainable operation of the EPOS RI. This paper has presented and discussed the EPOS approach to ensuring financial viability and tackling the challenge of long-term sustainability of the RI during its full operational phase.

The EPOS experience in addressing financial viability and RI sustainability confirms that substantial funding and support will be necessary in the coming years to reach full operation and ensure long-term sustainability. In order to ensure an adequate funding level, EPOS ERIC has to demonstrate to funders and contributors (national authorities and research organizations) that the RI construction has been successfully completed, exploitation is warranted, and impact is routinely assessed. The EPOS POP has been designed through a dedicated strategic plan to accomplish these tasks and, as shown in this paper, a three years' time window is necessary.

The EPOS approach to sustainability relies on the definition and the implementation of suitable models for each of the four qualifying dimensions (namely, governance, financial, legal, and technical dimensions) identified to guarantee the operation of the RI, considering the scientific innovation and impact as the overarching frame. This paper shows that these four dimensions are interdependent, although governance is considered as the qualifying dimension that gathers and connects the other three dimensions. Indeed, a suitable governance is necessary to manage the pan-European RI through the designed federated approach as well as to share resources and optimize investments also through the harmonization of national roadmaps and dedicated national RI budgets to support TCS and related EPOS services. The concept of host contribution and the role of hosting countries is considered essential to ensure long-term commitments for operating the core components located inside the EPOS ERIC perimeter.

The solutions identified to accomplish the sustainable operation of EPOS will be monitored through the landscape analysis designed to assess values and identify gaps in operating the EPOS RI. This will allow the implementation of the EPOS ERIC long-term sustainability plan, which is a key deliverable of the EPOS SP project. The implemented governance and financial models as well as the EPOS functional architecture corroborate that the operation of the EPOS RI is viable. However, the long-term sustainability of a pan-European research infrastructure like EPOS requires long-term commitments by national authorities and funding agencies, whose lifetime goes well beyond the cycles of updating national roadmaps to support the ERIC. Even if the solutions adopted by EPOS ERIC to tackle the long-term sustainability challenge will be proved workable, a sufficient stable investment environment will be necessary to allow the RI to concentrate on providing high quality services for their user communities instead of continuously looking for funding even for basic operations.

Acknowledgements. We wish to thank the people involved in the EPOS ERIC Service Coordination Committee, composed of TCS and ICS representatives, as well as those in the IT board for their valuable efforts to make the EPOS RI operational ensuring progress toward operation. Special thanks to all the EPOS supporters who worked in past years or are still working within thematic communities and ICS to build the EPOS RI sharing its vision and mission. We wish to thank Barbara Angioni for her support in the graphic design and for the figures. This work has received funds from the EC project EPOS SP (contract number 871121) funded in the framework of the Horizon 2020 program.

References

Atakan K., M. Cocco, B. Orlecka-Sikora, R. Pijnenburg, L. Ottemöller, T. Langeland, J. Michalek, C. Rønnevik, D. Olszewska, B. Górka-Kostrubiec, … (2022). National EPOS initiatives and participation to the EPOS integration plan, Ann. Geophys, this Volume.

Bailo, D., R. Paciello, M. Sbarra, R. Rabissoni, V. Vinciarelli, and M. Cocco (2020). Perspectives on the Implementation of FAIR Principles in Solid Earth Research Infrastructures, Front. Earth Sci., 8, 3, https://doi.org/10.3389/feart.2020.00003.

Bailo D., K. G. Jeffery, K. Atakan, L. Trani, R. Paciello, V. Vinciarelli, J. Michalek, A. Spinuso (2022). Data integration and FAIR data management in solid Earth Science, Ann. Geophys., this Volume.

Boeckhout M., G.A. Zielhuis and A.L. Bredenoord (2018). The FAIR guiding principles for data stewardship: Fair enough?, Eur. J. Hum. Genet., 26, 931-936, doi:10.1038/s41431-018-0160-0.

Cocco M., D. Bailo, R. Paciell, C. Freda and K. Jeffery (2019). The FAIRness horizon: from principles to practice, the EPOS experience in solid Earth science, Geophys. Res. Abstr., 21, https://meetingorganizer.copernicus.org/EGU2019/EGU2019-13137.pdf.

Cocco M., C. Freda, K. Atakan, D. Bailo, K. Saleh Contell, O. Lange and J. Michalek (2022). The EPOS Research Infrastructure: a federated approach to integrate solid Earth science data and services. Ann. Geophys., this Volume.

EGERIC Expert Group (2021). Assessment on the implementation of the ERIC regulation, European Commission, Directorate-General for Research and Innovation, https://data.europa.eu/doi/10.2777/747211.

Elixir (2019). ELIXIR's Long-term sustainability plan, https://elixir-europe.org/about-us/how-funded/sustainability-plan, https://f1000research.com/documents/8-1642.

EPOS ERIC Statutes (2018). Statutes of the European Plate Observing System — European Research Infrastructure Consortium (EPOS ERIC) (OJ C, C/423, 23.11.2018, p. 1, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018Y1123%2801%29.

EU Regulation No 723/2009 of 25 June 2009 on the Community legal framework for a European Research Infrastructure Consortium (ERIC) Current consolidated version: 26/12/2013 – ELI: http://data.europa.eu/eli/reg/2009/723/oj.

EU Regulation No 1291/2013 (2013). Establishing Horizon 2020 – the Framework Programme for Research and Innovation (2014-2020). Article 2 (6) 11 December 2013.

https://ec.europa.eu/research/participants/data/ref/h2020/legal_basis/fp/h2020-eu-establact_en.pdf

https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/our-digital-future/european-research-infrastructures_en

European Commission (2016). Directorate-General for Research and Innovation, European charter of access for research infrastructures: principles and guidelines for access and related services, Publications Office, 2016, https://data.europa.eu/doi/10.2777/524573.

European Strategic Forum on Research Infrastructures ESFRI Roadmap 2016. Strategic Report on Research Infrastructures, https://www.esfri.eu/roadmap-2016.

European Strategy Forum on Research Infrastructures Long-Term Sustainability Working Group (2017). ESFRI Scripta Volume II, ISBN Print: 978-88-901562-6-7, ISBN PDF: 978-88-901562-8-1, https://www.esfri.eu/sites/default/files/ESFRI_SCRIPTA_SINGLE_PAGE_19102017_0.pdf.

European Strategic Forum on Research Infrastructures (2018). ESFRI Roadmap 2018. Strategic Report on Research Infrastructures, http://roadmap2018.esfri.eu/media/1066/esfri-roadmap-2018.pdf.

European Strategic Forum on Research Infrastructures (2019). Annual Report 2017-2018, https://www.esfri.eu/sites/default/files/ESFRI_BiAnnual_Report_2017_2018.pdf.

European Strategic Forum on Research Infrastructures (2021). ESFRI Roadmap 2021, Strategic Report on Research Infrastructures, ISBN Print: 978-88-943243-4-1 ISBN PDF: 978-88-943243-6-5, https://roadmap2021.esfri.eu/media/1295/esfri-roadmap-2021.pdf.

Kutsch W.L., A. Asmi, P. Laj, M. Brus and S. Sorvari S. (2016). Environmental Research Infrastructures providing shared solutions for science and society, (ENVRIplus), Geophysical Research Abstracts.

Marti M., F. Haslinger, S. Peppoloni, G. Di Capua, H. Glaves, I. Dallo (2022). Addressing the challenges of making data, products, and services accessible: an EPOS perspective, Ann. Geophys., this Volume.

Mons B., C. Neylon, J. Velterop, M. Dumontier, L.O.B. Da Silva Santos and M.D. Wilkinson (2017). Cloudy, increasingly FAIR; Revisiting the FAIR Data guiding principles for the European Open Science Cloud, Inf. Serv. Use., 37, 49-56, doi:10.3233/ISU-170824.

OECD (2014). International Distributed Research Infrastructures: issues and options, OECD Committee for Scientific and Technological Policy, https://www.oecd.org/science/international-distributed-research-infrastructures.pdf

OECD (2017). Strengthening the effectiveness and sustainability of international research infrastructures, OECD Science, Technology and Industry Policy Papers, No. 48, OECD Publishing, Paris, https://doi.org/10.1787/fa11a0e0-en.

OECD (2019). Reference framework for assessing the scientific and socio-economic impact of research infrastructures, OECD Science, Technology and Industry Policy Papers, 65, OECD Publishing, Paris, https://doi.org/10.1787/3ffee43b-en.

OECD/Science Europe (2020). Optimising the operation and use of national research infrastructures", OECD Science, Technology and Industry Policy Papers, No. 91, OECD Publishing, Paris, https://doi.org/10.1787/7cc876f7-en.

Petzold, A., A. Asmi, A. Vermeulen, G. Pappalardo, D. Bailo, D. Schaap, H. M. Glaves, U. Bundke and Z. Zhao (2019). ENVRI-fair-interoperable environmental fair data and services for society, innovation and research. Proceedings – IEEE 15th International Conference on EScience, EScience, 824068, 277-280, https://doi.org/10.1109/eScience.2019.00038.

Philippin S., P. Laj, M. Ndisi, A. Dubost, S. Gagliardi and A. Tjulin (2019). ENVRIPlus project, RI strategy for flexibility and sustainability: Governance for sustainable and adjustable access to RIs, https://mediawiki.envri.eu/images/c/c8/D10.4._RI_strategy_for_for_flexibility_and_sustainability.pdf.

Sorvari S., W.L. Kutsch, P. Laj, A. Asmi and M. Brus M. (2016). ENVRI Cluster – a community-driven platform of European environmental research infrastructures for providing common solution for science and society, Geophysical Research Abstracts, 18, EGU2016-15226, https://meetingorganizer.copernicus.org/EGU2016/EGU2016-15226.pdf.

Van Belle J., J. van Barneveld, B. V. Bastiaanssen, A. Buitenhuis, L. Saes and G. van Veen (2018). ICOS Impact Assessment Report, technopolis group August 2018, https://www.icos-cp.eu/sites/default/files/2018-09/ICOS_Impact_Assessment_Report_2018.pdf

Wilkinson, M. D., M. Dumontie, Ij. J. Aalbersberg, G. Appleto, M. Axton A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, P. E. Bourne, J. Bouwman, A. J. Brookes, T. Clark, M. Crosas., I. Dillo, O. Dumon, S. Edmunds, C. T. Evelo, R. Finkers, … B. Mon (2016). The FAIR Guiding Principles for scientific data management and stewardship. Sci. Data, 3, 160018, https://doi.org/10.1038/sdata.2016.18

Wessels R., G. ter Maat, E. Del Bello, L. Cacciola, F. Corbi, G. Festa, F. Funiciello, G. Kaviris, O. Lange, J. Lauterjung, R. Pijnenburg, G. Puglisi, D. Reitano, C. Rønnevik, P. Scarlato, L. Spampinato (2022). Transnational access to facilities for Solid Earth Sciences: a service to promote 1 multi-domain research in Europe. Ann. Geophys., this Volume.

Wilkinson M.D., S.A. Sansone E. Schultes, P. Doorn, L.O.B. Da Silva Santos and M. Dumontier (2018). Comment: A design framework and exemplar metrics for FAIRness, Sci. Data, 5, doi:10.1038/sdata.2018.118.

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