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On the Sustainable Operation of Dynamic Risk Services Within EPOS

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1. Introduction

This document describes the context of 'sustainable operation' of services within the EPOS framework, together with suggestions how to assess sustainability from a service operation perspective, related to the dynamic risk services that have been developed within the RISE project, and that are expected to be sustainably operated long term within the framework of the EPOS research infrastructure.

EPOS, the European Plate Observing System (www.epos-eu.org) is the European Research Infrastructure for solid Earth sciences. It is organised at its core as a European Research Infrastructure Consortium (ERIC), and encompasses the different sub-domains of solid Earth sciences (geology, volcanology, geodesy, seismology, ...) as well as different infrastructure components (near-fault observatories, multi-scale laboratories, satellite data services, ...) as so-called Thematic Core Services.

RISE focuses on real-time earthquake risk reduction, and one yet not fully resolved challenge for a scientific research infrastructure like EPOS is the role of such a European-level infrastructure and its services in (near) real time contexts, where usually responsibilities are firmly embedded within national entities and processes. Nevertheless, harmonisation and standardisation of services and their operation, and in particular their scientific background, on a pan-European scale, is key to ensure that these services are based on common best practices and state-of-the-art of the underlying science, thus improving credibility, transparency and trust for all stakeholders.

One important element of such services and their use for society is the sustainability of their operation, and this deliverable addresses that particular aspect for the dynamic risk services developed within RISE.

2. Sustainable Service Operation in Context

The term '**sustainability**' came to fame over the last decades in the context of human-environmental interactions, where it basically translates to "*acting / behaving (to meet current needs) in a way that doesn't compromise the abilities to meet future needs*". Current use of the term is often strongly linked to the concept of sustainable development as introduced by the UN Commission on Environment and Development (Brundtland Commission) in 1987. Its historic origins are usually traced back to forestry, where the German administrator von Carlowitz used it in his 1713 work *Silvicultura Oeconomica* to describe the use of a natural resource (forest) in a way that ensured the existence and usability of the resource (forest) over the long term (see for example *https://en.wikipedia.org/wiki/Sustainability* and references there).

With a broader scope the term is today used exhaustively in many different contexts with a rather fuzzy interpretation as "*ability of keeping something 'up and running' for the foreseeable future*".

Sustainability is also addressed in the context of Research Infrastructures (RIs), notably in a number of documents by OEDC (e.g. OECD, 2017) and the European Commission (European Commission (EC), 2016, 2017, and https://research-and-innovation.ec.europa.eu/strategy/strategy-2020-2024/our-digital-future/european-research-infrastructures/long-term-sustainability_en). EC (2017) cites the OECD-adopted definition of sustainability for RIs as "*the capacity for a research infrastructure to remain operative, effective and competitive over its expected lifetime*" (OECD, 2017) and notes several dimensions of sustainability in addition to sustainable funding, "*such as scientific excellence, socio-economic impact, or innovation*". These dimensions are broken down into more detail both in OECD (2017) and EC (2016). OECD (2017) identifies the following major elements of RI sustainability for the operational phase as

- *Scientific excellence,*

- *Governance,*
- *Financing and funding models,*
- *Cost optimization,*
- *Risk and upgrade management,*
- *Data management,*
- *Human resources and staff policies,*
- *Users' interests and access policies,*
- *Innovation and technology transfer,*
- *Public awareness and outreach;*

whereas EC (2017) states pre-conditions for long-term sustainability of RIs as

- *Ensuring Scientific excellence,*
- *Managing tomorrow's RI - Skills of managers, operators and users,*
- *Unlocking Innovation potential of RI,*
- *Measuring socio-economic impact of RI,*
- *Exploiting better the data generated by the RI,*
- *RI Life cycle – Upgrading of RI,*
- *RI Life cycle – Decommissioning of RI,*
- *Ensuring sustainable governance of RI,*
- *Funding the construction and operation of RI,*
- *Structuring the international dimension of RI.*

While both identify 'Scientific Excellence' as the most important aspect, the ranking in those lists is apparently quite arbitrary, and, while worded differently, most of the elements are present in both.

Already in 2015, the European Intergovernmental Research Organisation Forum (EIROforum www.eiroforum.org) published a discussion paper *What makes Research Infrastructures sustainable in the long term?* (EIROforum, 2015), that identifies five main criteria for enabling long term sustainability of RIs, which can be interpreted both as a grouping and a priorisation of the 10 elements each cited above:

1. *Relevance of an RI to its scientific community and the ability to generate scientific excellence;*
2. *Sustainable governance model and legal framework;*
3. *Sustainable funding model;*
4. *Ability to attract scientific talent and build a critical mass of scientific expertise;*
5. *Socio-economic impact.*

All these resources look at RIs on an institutional scale, however, so some care is needed when translating those sustainability drivers for RIs to specific data and product services, as is the purpose of this paper.

According to the EPOS architecture, described for example in the *Scientific and Technical Description of EPOS* (EPOS 2017), data and product services are under the governance of specific Thematic Core Services (TCS) and operated by designated service providers. These service providers usually are scientific / academic institutions like universities or national services. As the specific data and products services form the key building blocks of the EPOS RI, the RI-level sustainability aspects of course connect also to the services, but the sustainable operation of a service in the EPOS framework can, in our view, fortunately be assessed quite comprehensively based upon a few concrete elements. We denote those as *technical, scientific and operational sustainability*, and further describe their assessment below.

3. Dynamic Risk Services for Seismology

3.1 RISE Developments and EPOS Integration

The RISE project aims at a paradigm shift in assessing earthquake hazard and risk: from '*constant in time*' to '*evolving, integrated and dynamic*'. Dynamic earthquake risk assessment, therefore, considers time-variable geophysical conditions (e.g., earthquake occurrence probabilities, reflected in a time-dependent 'short-term' seismic hazard assessment) as well as time-variable 'risk factors' like changing vulnerability (e.g., pre-damaged buildings) and exposure (e.g., building occupancy).

Somewhat simplified, the goal of scientific research (projects) is to ask and answer specific scientific questions, thus generating new knowledge and producing information from data and models, that can be captured in a variety of ways and formats, while the goal of (scientific) services then is to provide structured and standardised access to such information, but also to the underlying data and models. RISE covers and directly connects both, the scientific development of methods and algorithms (workflows) to generate information on time-dependent assessment of various aspects of earthquake risk, and embedding these developments in operational services, usually IT implementations, with appropriate architecture and infrastructure. In order to ensure their long-term stable and sustainable operation and further development, the services resulting from RISE are expected to be integrated as part of EPOS, as sustainable service operations is one of the key elements of this research infrastructure.

EPOS as RI provides (a) an organisational framework for technical, financial and legal integration of domain-specific services in Earth sciences (EPOS architecture); (b) a centralized IT architecture for harmonised and interoperable discovery and access to assets (data, products, services) (ICS-C); (c) a connection to distributed specialized IT infrastructures for specific tasks (e.g., HPC applications, hosting of visualization or computation applications) (ICS-D, in build-up phase).
The initial integration of the first domain-level TCS services with the developing ICS-C platform was achieved with a rather ad-hoc approach during the EPOS-IP project. As part of its Implementing Rules, EPOS is at the moment elaborating guidelines for future service integration of TCS-provided services, and their formal acceptance as EPOS services. These EPOS Implementing Rules are expected to become effective during 2023, upon approval by the EPOS-ERIC General Assembly. The following checkpoints for accepting TCS provided services in EPOS are envisioned:

- *Service is compliant with the set of technical requirements defined for the inclusion of the service in the EPOS Data Portal.*
- *Service is compliant with the EPOS Data Policy.*

The TCS Services:

- *have an identified user community;*
- *are approved by the TCS;*
- *have identified service providers approved by the TCS consortium;*
- *are integrated into the ICS;*
- *have a planned minimum time duration of 5 years;*
- *ensure (best effort) continuous service with quantified service level target;*
- *have mechanisms to report service level.*

For RISE, the most relevant TCS is EPOS Seismology (Haslinger et al., 2022). It encompasses three pillars, which in turn are organizing the data, products and service provisioning of their realm - ORFEUS for waveform services and related derived products, EMSC for seismological products like earthquake parameters, EFEHR for seismic hazard and risk products and services. The overall RISE-EPOS integration is described in the RISE deliverable D1.13 *Strategic Integration of RISE Activities with EPOS* (revised 31-03-2022).
By nature, the *'dynamic risk services'* developed within RISE fall in the realm of EFEHR, and indeed they were developed in close connection with EFEHR through the course of the project. As hazard

and risk assessment usually is at the end of the chain with regard to seismological data interpretation, some services will rely on direct connection to 'feeding' services also from other pillars.

Significant progress has been made within RISE towards the implementation of operational dynamic risk services. RISE Deliverable D6.5 *Report on the Development of RLA, EEW and OEF at European Scale* (28-02-2023) summarizes the status achieved of the Rapid Loss Assessment (RLA), Earthquake Early Warning (EEW) and Operational Earthquake Forecasting (OEF) capabilities at a European level.
At the same time, as part of the Horizon2020 EPOS Sustainability Phase project (EPOS SP, https://www.epos-eu.org/projects/epos-sp) the role of the EPOS research infrastructure in providing (seismic) hazard and risk assets and their value for society was investigated (EPOS SP D6.3 *EPOS hazard and risk values for society*, 208-10-2022). One of the main challenges identified there was the lack of (legal) mandate on the EPOS RI or TCS level for the provision of services to customers like civil protection authorities or even the general public in particular in quasi near-real-time settings (e.g., up-to-date event impact assessment). Here, existing national legislation and nationally defined mandates need to be respected. The consequence for dynamic risk services within EPOS is that EPOS and its TCS focus on the provision of scientific background services to support the delivery of state-of-the-art, harmonised and coherent information by those nationally mandated institutions. RISE deliverable 6.4 *A User-Centric Dynamic Risk Framework for Switzerland* (28-02-2023) describes such a national implementation of the various RISE developments.

Overall, RISE contributed to and developed the following services addressing dynamic earthquake risk:

An **Operational Earthquake Forecasting and Operational Earthquake Loss Forecasting service** has been implemented for Italy, as documented in RISE deliverable D6.2 *Report on testing OEF and extending earthquake forecasts to loss forecasts in Italy* (28-02-2023), and is underway for Switzerland, as described in RISE deliverable D6.4. The national implementations serve as basis for a harmonised implementation of OEF/OELF across Europe, as outlined in RISE deliverables D8.9 *Operational Earthquake Forecast Services in Italy, Switzerland and Europe* (23-05-2023), D4.3 *Operational earthquake loss forecasting for Europe* (15-12-2022) and D6.5.

A **European platform for evaluating earthquake forecasts** has been developed and initially set up as part of the Collaboratory for the Study of Earthquake Predictability (CSEP) at GFZ Potsdam, offering a significantly improved framework for transparent and traceable decentralized testing, thus promoting best practices in open science (RISE deliverable D8.7 *EU forecast testing center operational,* 28-02-2023).

A **European Rapid Loss Assessment** (RLA) system demonstrator has been developed and published on an open GitLab repository. As described in RISE deliverables D6.5 and D8.8 *European Rapid Loss Assessment Operational - Demonstrator* (28-02-2023), it builds on the European Seismic Hazard / Risk Models 2020 (ESHM20, ESRM20) and the RISE-supported developments of harmonised European ShakeMap services. A national implementation following this demonstrator has been developed for Switzerland where it is currently under advanced testing by the responsible national agency, the Swiss Seismological Service at ETH Zurich.

A **user-ready risk-cost-benefit analysis framework** to support decision making has been developed and exhaustively documented in RISE deliverable D4.7 *Good-practice report on risk-cost-benefit in terms of socio-economic impact* (28.02.2022). It describes in detail the contribution of the various RISE developed dynamic risk services to Cost Benefit Analysis (CBA). Noting the shortcomings of CBA that only allows to consider monetary (economic) terms, the Multi Criteria Decision Analysis (MCDA) is introduced as more suitable framework for supporting decision making and in particular selecting between alternatives, given a set of criteria going beyond the purely monetary.

As already noted above, the continued sustainable operation of these RISE developed services, frameworks and platforms is a task and responsibility for the thematic scientific community that can ensure scientific integrity and credibility as part of its participation to the EPOS RI, here the EFEHR pillar of the EPOS Seismology TCS. To a large extent, these efforts are part of the normal operation of EFEHR and thus supported by the contributions to EFEHR operation by its members as well as EPOS-ERIC. In addition, the EU HorizonEurope project GeoInquire (www.geo-inquire.eu, 10-2022 to 9-2026) includes further development of some RISE developed services as well as general strategies for improving performance monitoring and FAIRness assessment for data and services, thereby again supporting their sustainability.

3.2 Sustainable Operation of Dynamic Risk Services within EPOS

Realizing that the dynamic risk services developed within RISE are just at the beginning of their operational life, their future sustainable operation will need to be carefully assessed and managed. To support this endeavour, the following provides a brief summary and framework of aspects of sustainable service operation.

When considering '*sustainable*' operation of services, we understand *sustainable* close to its traditional meaning of '*having the prospect of continuing to exist / operate over time*'. In the context of services for scientific data and products, this understanding of sustainability can then be broken down further into

- *technical sustainability*: the technical implementation of the service is stable and set up in such a way that the service can be continued to operate in future (concerning hardware / infrastructure and software; including documentation, concepts for relevant bug fixes and operational upgrades). This also includes connections to relevant / required input of data / information from other services or sources. Mechanisms are in place to monitor and guide the performance and development of the technical implementation.
- *scientific sustainability*: the scientific methods and algorithms behind the service are properly documented and community vetted / approved. Mechanisms are in place to monitor relevant scientific developments and guide potential methodological adaptations of the service.
- *organisational (operational) sustainability*: the continued operation of the service is secured in terms of availability of resources (people and infrastructure) and commitments of service providers. Mechanisms are in place to monitor and if needed adapt the organisational / operational setup (e.g., change service providers).

Common to all three sustainability elements is the need for a mechanism to monitor and guide, which is a core task of the governance of a service. As stated above, the dynamic risk services developed within RISE naturally attach organisationally to EFEHR, and, therefore, implementing an adequate governance for these services is a task for the EFEHR consortium.

Two other aspects that are not directly part of 'sustainability' but closely linked should also be considered in the long-term:

- *relevance*: is the service used (at all / as expected)
- *obsolescence*: is it possible to continue to provide the service (different aspects: loss of relevant input information, invalidation of scientific background, unsupportable cost of operation, …)

For newly established services these aspects can of course not be assessed immediately, but they should be regularly monitored through the service governance mechanisms. Monitoring of *relevance* can be supported by appropriate performance indicators, while *obsolescence* likely will need to be monitored through periodic assessments of its different aspects.

At the start of the assessment of operational or sustainability issues of any service, some basic requirements for the service should be checked:

- service content:
  - a description of what the service does / delivers in terms of input, (processing) workflow, output) is available;
  - the metadata for the service and the service output (including data format, identifier, license) is defined (following appropriate standards) and available;
  - any external input (data) needed to operate the service has appropriate licenses or usage agreements.
- service functionality:
  - the way how users can interact with the service is defined and described (API, webservice, GUI, ...), if needed with additional training material;
  - access restrictions (if any) are well defined and, if needed, appropriate access control mechanisms are in place.

Considering the above criteria and requirements will ensure that sustainability of the dynamic risk services developed within RISE is adequately addressed in their further operationalisation as part of the EPOS evolution.

4. Conclusion / Outlook

Over its 45 months, RISE has significantly progressed the scientific foundation and state-of-the-art of dynamic earthquake risk assessment. From improving earthquake locations and earthquake forecasts, producing better and more harmonised ground-shaking estimates, to translating that into time-dependent earthquake loss estimates that are also backed by novel ways of assessing exposure, to finally combining all those elements into decision support frameworks that go beyond classical cost-benefit analysis, RISE has demonstrated what is possible today and showed what may be possible in future. Many of the dynamic risk assessment tools and methods were tested and validated either on specific use cases or on national scales. The operationalisation of European level services within EPOS, however, has met some challenges, from the fact that EPOS was for most of the duration of RISE still under development to the realisation that services that are mainly targeting decision makers and often in emergency situations are quite different in their operational requirements than more fundamental scientific services. Nevertheless, RISE was firmly embedded in the EPOS framework by its direct connections to the relevant EPOS thematic core services, and in particular the European Facilities for Earthquake Hazard and Risk EFEHR, as one pillar of EPOS Seismology, will carry the further European-level harmonisation and integration of these services forward. Besides the continuation of RISE achievements as part of EFEHR operation, the recently started Horizon Europe project GeoInquire (Geosphere INfrastructures for QUestions into Integrated REsearch) will further enhance some of the RISE developed services in the EPOS context.

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RISE deliverables

Deliverable 1.13, Haslinger et al. (2022) (revised version) "Strategic Integration of RISE services within EPOS"

Deliverable 4.3, Chioccarelli et al. (2022) " Operational earthquake loss forecasting for Europe"

Deliverable 6.2, Chioccarelli et al. (2023) "Report on testing OEF and extending earthquake forecasts to loss forecasts in Italy"

Deliverable 6.4, Boese et al. (2023) "A User-Centric Dynamic Risk Framework for Switzerland"

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Deliverable 8.9, Sarson et al. (2023) "Operational Earthquake Forecast Services in Italy, Switzerland and Europe"