PART2

LANDSCAPE ANALYSIS

SECTION3

RELEVANCE & IMPACT

The Section 3 of the Landscape Analysis focuses on the Research Infrastructure services and their broader impacts, describing not what the landscape is, but what it can do. As it is not feasible to demonstrate comprehensively in such a document the broad range of impact areas where Research Infrastructures make a relevant contribution, this section has been developed in the form of selected examples.

The following impact areas are addressed:

ESFRI RIs FOR SUSTAINABLE DEVELOPMENT GOALS

ESFRI reflects in its White Paper that the European landscape of Research Infrastructures addresses the overall objectives of the new European Research Area (ERA) and is being constantly optimised producing new science to tackle new societal challenges and to contribute to the global Sustainable Development Goals (SDGs). The SDGs have become the world's shared framework for sustainable development and call for actions by all the actors of the society, including science and research. A holistic framework for action that reduces the complexity and encompasses the 17 SDGs and their 169 Targets was suggested by the UN Sustainable Development Solutions Network in the paper Six transformations to achieve the Sustainable Development Goals published in the journal Nature Sustainability in August 2019[1].

These six SDG Transformations are suggested as modular building-blocks of SDG achievement: (1) education, gender and inequality; (2) health, well-being and demography; (3) energy decarbonisation and sustainable industry; (4) sustainable food, land, water and oceans; (5) sustainable cities and communities; and (6) digital revolution for sustainable development.

The impact of the ESFRI Research Infrastructures reaches all these six transformations. ESFRI Research Infrastructures cover most scientific fields, from Social Sciences & Humanities via Health & Food and Environment to Energy and Physical Sciences & Engineering, and thanks to synergies and interdisciplinary research, they generate knowledge and impact in all these fields including the interface between different disciplines. This is why, by using synergistically their capacities from all scientific fields, ESFRI Research Infrastructures have high potential to address complex phenomena like grand societal and scientific challenges – e.g. climate change, population increase and differential ageing, food and energy sustainability. Of the identified 17 SDGs, all of them are addressed by the European Research Infrastructures, and are linked directly or indirectly to the research conducted within them. Therefore, following the Transformations approach described earlier, which identifies synergies in the sustainable development pathways, this chapter focuses on inter-relationships and multiple benefits which ESFRI Research Infrastructures provide in achievement of strongly interdependent SDGs. Keeping in mind that the SDGs can be addressed in parallel in several transformations, only the most relevant SDGs and contributions of Research Infrastructures will be highlighted in this Chapter. It is also important to mention that the transversal SDGs (16) Peace, Justice, and Strong Institutions and (17) Partnerships for the Goals, and the Research Infrastructures' input for their achievements are considered in articulation with all the transformations and are applicable to all the Research Infrastructures in all scientific fields. Therefore, in order to make the overview of the contributions of the Research Infrastructures to the achievements of the SDGs systematised and structured, the relevant SDGs will be presented in this Chapter in the following way:

Transformation 1: education, gender and inequality
SDG (1) No Poverty, (4) Quality Education, (5) Gender Equality, (8) Decent Work and Economic Growth, (10) Reducing Inequalities

Transformation 2: health, well-being and demography
SDGs (2) Zero Hunger, (3) Good Health and Well-being

Transformation 3: energy decarbonization and sustainable industry
SDGs (7) Affordable and Clean Energy

Transformation 4: sustainable food, land, water and oceans
SDGs (6) Clean Water and Sanitation, (13) Climate Action, (14) Life Below Water, (15) Life On Land

Transformation 5: sustainable cities and communities
SDGs (11) Sustainable Cities and Communities, (12) Responsible Consumption and Production

Transformation 6: digital revolution for sustainable development
SDGs (9) Industry, Innovation and Infrastructure

Transversal SDGs
(16) Peace, Justice, and Strong Institutions, (17) Partnerships for the Goals

1. Six Transformations to achieve the Sustainable Development Goals. Sachs, J.D., Schmidt-Traub, G., Mazzucato, M. et al. Nat Sustain 2, 805–814 (2019) https://www.nature.com/articles/s41893-019-0352-9?proof=t

TRANSFORMATION 1
EDUCATION, GENDER AND INEQUALITY

ESFRI Research Infrastructures from all the research fields are strongly supporting the implementation of these SDGs and promote through their organization education, gender equality, and lower inequalities thus contributing to economic growth and elimination of extreme poverty. All ESFRI Research Infrastructures, along with running programs for training students and professional researchers, propose multiple education programmes, very often focused on school-age children, as well as teacher training programs at regional, national, and international levels. ESFRI Research Infrastructures put in their recruitment strategies the objective of gender balance and support all the initiatives which aim at reducing inequalities (e.g. working with refugees and people with disabilities). The Social Science domain has been selected here to illustrate remarkable contributions to this group of SDGs within *Transformation 1*.

CLARIN ERIC contributes directly to SDGs (4), (5) and (8) with its language resources which provide an easy-to-use infrastructure with digital artefacts and contribute to increasing the number of adults with relevant skills for decent jobs and digital literacy; online availability of these artefacts contributes to equal access, including people with disabilities. CLARIN datasets can be used to develop and evaluate Machine Translation or Automatic Text Simplification technologies, which can contribute to the promotion of secure working environments for migrant workers, and to the promotion of tourism, local culture and products.

The **European Social Survey ERIC** addresses all of these SDGs (1), (4), (5), (8), (10) not only tapping them individually but allowing cross domain and often across time analysis. ESS includes detailed measurement of highest level of education assessed in relation to a wide variety of other outcomes from health, well-being or economic inequality. ESS allows gender analysis of all of its data and in 2023 will include its first dedicated module on the topic 'Gender in Contemporary Europe: Rethinking Equality and the Backlash'. The module will measure five dimensions: identity, sexism, experiences, salience and policy instruments.

TRANSFORMATION 2
HEALTH, WELL-BEING AND DEMOGRAPHY

These SDGs can be achieved within *Transformation 2* and key investments in health and well-being. The Research Infrastructures in the field of biology and health are the most natural supporters of this group of SDGs.

MIRRI can contribute to deliver the impacts of the SDG (3), mostly on tackling epidemics of major communicable diseases by performing research on pathogenic microorganisms and human infectious diseases. It also develops new (bio)pharmaceuticals/ therapeutic solutions, including antimicrobials, vaccines, phage therapies and microbiome therapeutics. By collaborating on the research and development of new, safe and healthy food products, or on delivering resources and methods for biological management of soils and crops, MIRRI can contribute to promoting sustainable food production systems and access to safe, nutritious and sufficient food.

EATRIS ERIC, which mission is to accelerate the translation of scientific discoveries into patient benefit, contributes directly to the SDG (3). EATRIS supports early stages of health and medicines research where the risk of failure to reach the patient is particularly high and where there is a crucial need for cross-sectoral and multi-disciplinary collaboration.

Euro-BioImaging ERIC is particularly well aligned with SDG (3), as its users are especially engaged in research that aims to elucidate mechanisms for cell regulation and survival, disease development and aging mechanisms, as well as diagnostics, and therapeutic intervention. Equally relevant is Euro-BioImaging's contribution to achieving SDG (2), as imaging of, for example, plant cells can provide important insight on nutritional composition, adaptation to extreme conditions, or phenotypic changes driven by genetic engineering.

ELIXIR contributes to SDG (2). Successful applications of bioinformatics to food production are used in farming and agriculture – e.g. crop and breeds development, pest and pathogen control – and are key to ensuring security of food supplies globally, including facing climate and environmental change. Bioinformatics applications are well recognised in the area of health, and range from disease diagnostic and prevention to epidemics preparedness and response, personalised medicine, and the development of new drugs and treatments.

INFRAFRONTIER contributes to Goal (3) particularly to the targets related to fighting pandemics and epidemics and non-communicable diseases, securing access to affordable medicines and vac-

cines and reduce the effects of hazardous environmental agents on health.

ESFRI Research Infrastructures from the domain of Environmental Sciences and Physics are also significant contributors to this group of SDGs.

ACTRIS brings elements that contribute to Goal (2). Capacity to forecast weather and weather extremes assist farmers to their operational decisions. In addition, tracking the deposition of specific compounds present in the particulate phase or gas phase, which have serious impacts on ecosystems' health, the quality of soils and waters and, directly or indirectly, on agricultural production. For ACTRIS better climate forecasting will be key to anticipate the key risks that climate poses to public health in particular countries and regions.

The technologies, know-how and scientific advances behind accelerator-based high-energy physics have historically produced numerous applications in medicine. The ultrafast and extremely brilliant X-ray pulses generated in fast succession by the **European XFEL** enable insight into the atomic structure of pathogenic viruses, bacteria, and their proteins in unprecedented detail. Structural data of pathogens relevant for infectious diseases and noncommunicable diseases such as cancer can inform the development of effective vaccines and medication. Scientists can also use the European XFEL to explore the dynamics of biological reactions, gaining information into, for example, how drug molecules interact with pathogens in order to develop strategies to circumvent antimicrobial resistance.

The development of new-generation superconducting magnets and other technologies in the framework of the **HL-LHC** project of CERN brings the potential of very relevant applications to imaging and facility for cancer therapy.

Examples can also be given for the domain of Social Sciences & Humanities.

DARIAH ERIC contributes to SDGs (2) and (3) providing an unprecedented data and methodological resource base for pursuing these questions, significantly supplementing existing resources for incorporating cultural and historical perspectives into research.

SHARE ERIC is the largest pan-European social science panel study providing internationally comparable longitudinal micro data which allows insights in the fields of public health and socio-economic living conditions of European individuals, both for scientists and policy makers.

The **European Social Survey ERIC** also contributes to SDG (3) providing a comprehensive comparative pan-European dataset on the social determinants of health and health inequalities including both physical and mental health, combining rich data on living conditions, with a variety of lifestyle factors and health outcomes.

TRANSFORMATION 3
ENERGY DECARBONISATION AND SUSTAINABLE INDUSTRY

This SDG can be achieved via *Transformation 3* ensuring universal access to modern energy sources, decarbonizing the energy system and reducing industrial pollution. The most relevant contributors to the implementation of this SDG are the Research Infrastructures from energy research field. The Research Infrastructures from the field of Social Sciences are important actors as well monitoring the societal attitude towards this issue.

MYRRHA will contribute in several manners to the international nuclear landscape and beyond and to SDG (7) by offering a solution for the elimination of nuclear waste by performing the transmutation of its very long-lived nuclear isotopes into short-lived ones and by providing a method for better utilisation of nuclear fuels.

EU-SOLARIS is focused on Concentrated Solar Power / Solar Thermal Electricity (CSP/STE). CSP/STE is a possible key future technology for the decarbonisation of the energy sector and the mitigation of the climate change through the reduction of greenhouse gas emissions from fossil fuels currently used to generate electricity. Each square metre of CSP mirror surface, for example, may be enough to avoid 200 to 300 kilograms of CO_2/year.

The **European Social Survey ERIC** module on climate change and energy was designed to inform policy makers on the public component of the transition to a low-carbon Europe by making a systematic and detailed comparison of attitudes to climate change, energy security and energy preferences and to examine the relative importance of individual-motivational versus national-contextual variables in public energy preferences.

TRANSFORMATION 4
SUSTAINABLE FOOD, LAND, WATER AND OCEANS

These SDGs are aimed by *Transformation 4*. They focus on integrated strategies on sustainable environment, land-use and oceans healthy for people. The most relevant contributors to the implementation of these SDGs are the Research Infrastructures from the research fields of environment.

IAGOS has provided continuous measurements of greenhouse gases and short-lived climate forcers on the global scale over more than 25 years. Being relevant to SDG (15), with respect to their reference to Air Quality issues, IAGOS provides essential information on the composition of the atmosphere over different regions. IAGOS data contribute to the improvement of air quality models allowing monitoring and forecast, and assessment of mitigation scenarios. IAGOS participates in projects on the impact of aviation on climate, it can play an important role in helping aviation industry to develop along a more environmentally sustainable path.

ACTRIS and **ICOS ERIC** are also a good example of a pan-European Infrastructures particularly relevant to the SDG (13), where the community's challenge is to provide decision makers with the scientific analyses they need to adapt to climate change impacts and build climate resilience.

EURO-ARGO ERIC as part of Argo international network creates a full-depth, fully global, multi-disciplinary ocean/climate observing system to document the physical and biogeochemical ocean state and its evolution, including global ocean warming, sea level rise, acidification, deoxygenation, and the changing carbon cycle, significantly contributing to SDG (13).

EMBRC ERIC aims to answer fundamental questions regarding the health of oceanic ecosystems in a changing environment, support life-science breakthrough discoveries with the use of marine biological models, and continue long-term marine monitoring efforts. EMBRC ERIC is a driver in the development of blue biotechnologies, supporting both fundamental and applied research activities for sustainable solutions in the food, health, and environmental sectors.

TRANSFORMATION 5
SUSTAINABLE CITIES AND COMMUNITIES

These SDGs are in particular in focus of *Transformation 5* which strives for economically productive, socially inclusive and environmentally sustainable urban areas.

Helping planners to make cities more resilient to respond to heatwaves and associated impact on air quality, ACTRIS supports policies for air quality improvements.

EPOS ERIC, the European Plate Observing System, addresses SDG (11), contributing specifically to the indicator 11.b "By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030, holistic disaster risk management at all levels".

DARIAH ERIC Working Group on Digital Practices for the Study of Urban Heritage focuses on the study of digital methods and good practices of heritage and urban change, impact of urban development on cultural heritage as well as the identity of the city and the role of civil society. It reflects on the resilience of smart systems promoted today for user-personalization when interacting with city infrastructures.

TRANSFORMATION 6
DIGITAL REVOLUTION FOR SUSTAINABLE DEVELOPMENT

This SDG is aimed by *Transformation 6*, which focuses mainly on digital technologies and innovation. All the Research Infrastructures provide inputs to the digital transformation and the innovation-driven economy's growth, aligned with the European research and innovation strategy. A few examples from the domains of physics and medical research are given below to illustrate it, whereas a separate chapter which follows in this section treats particularly contribution of Research Infrastructures to digital transformation.

The research carried out at the **ILL** covers the full innovation cycle from fundamental research to technological application. The topic of materials for innovative and sustainable industry is relevant also for ESRF. The **ESRF EBS** is uniquely poised to support European industrial leadership on the circular economy and carbon-free life styles. Its unprecedented sensitivity and precision in advanced characterisation provides the researchers and industry with multi-scale insight from the atomic to the macro scale into materials and products, as they are processed, as they age and are reused, fuelling the virtuous innovation cycle of materials making, characterising and modelling.

The **European Spallation Source ERIC** is working with more than 40 European partner institutions and more than 130 collaborating institutions worldwide under the in-kind model. With the in-kind model, partners supply equipment, design documentation, personnel or other services to support the construction of ESS. The model ensures that key technologies are cultivated and enhanced in member states supporting national institutes and industry thus fostering the European industry.

EATRIS ERIC has been leading the establishment of a global repurposing hub, whose aim it is to bring together global resources to collaborate and support high potential projects with high unmet medical need. EATRIS initiates and facilitates academia-industry collaborations between SME, large pharma and EATRIS member institutes. It supports the operations of Innovation Hubs, such as the EATRIS-GSK Imaging Hub, an international multi-site collaboration hub for the development of advanced imaging tools.

TRANSVERSAL SDGs

Number (16) and (17) are the SDGs relevant to all Research Infrastructures in all scientific fields. These SDGs seek to promote peaceful and inclusive societies. These goals are in the heart of all the Research Infrastructures which by nature are remarkable examples of pan-European cooperation, as highlighted in some of the contributions below.

ELT at ESO, as one of the first intergovernmental scientific organisations, created by a treaty between Member States, represents a model for peaceful scientific cooperation between nations. CERN is another international organisation which promotes scientific collaboration and the values of science across governments and other stakeholders. In particular, the **HL-LHC** is being carried out as an international project with participants from all over the world. Besides, a project like HL-LHC requires strong partnership with industry, with significant knowledge transfer from research to the private sector.

EMSO ERIC is another excellent example of partnerships for the goals. It strongly supports the participative and transformative principle that underpins the UN Decade of Ocean Science for Sustainable Development.

A significant part of data integrated into **CLARIN ERIC** comes from parliaments and other public institutions. By providing sustainable access to such data in structured, annotated and unaltered form, adapted for automatic processing (easily searchable and retrievable), CLARIN contributes to targets related to SDG (16).

This short insight into the inputs of the Research Infrastructures to the agenda of the sustainable development reflects the crucial issue that all the Sustainable Development Goals are relevant and that most of the Research Infrastructures contribute to the development of several SDGs at the same time and with a very high impact. The ESFRI Research Infrastructures have demonstrated to be important tools to achieve the transformations required to realize the United Nations' Sustainable Development Goals for a better and more sustainable future for all by 2030.

ESFRI RIs IN RESPONSE TO EMERGENCIES

EXAMPLES FROM THE COVID-19 CRISIS

ESFRI RIs demonstrated an enormous capacity to respond to the emergency represented by COVID-19 pandemics, by rapidly revising/adapting their access programmes operations and delivering their services, including *ad hoc* new services to support research related to COVID-19.

RIs in the health domain were at the forefront and immediately acted, being able to offer all the necessary services in the whole pipeline of vaccine and therapeutics development, for the research on diagnostic tools and the analysis of the direct and indirect impact of the crisis. To facilitate COVID-19 related research, fast-track access calls were issued and publicized through the RIs websites, which were continuously updated. The information was also promptly collected on the Life Sciences Research Infrastructures (LS RIs) website[2] providing the users community with a comprehensive set of available services and resources. ESFRI also gathered information on COVID-19 related activities on its website[3].

Open Science data were at the base of success stories since the current pandemic started – the genome of the SARS-CoV-2 virus was sequenced much quicker than for previous similar pathogens (such as MERS-CoV and Ebola) and deposited in the public domain. This allowed other scientists to start studying the virus and tracking its spread. Likewise, research data on the COVID-19 disease has been readily made available in the public domain, thereby helping our clinical understanding of its effects, and informing the development of treatments and tracking new variants of the virus through genomic sequencing and coordinated data-sharing efforts. **ELIXIR** has played a key role in mobilizing public data infrastructure to enable research data-sharing via the COVID-19 Data Portal[4], a single entry point that provides free and open access to viral sequence data and other relevant data including proteins, imaging, expression data and literature relating to COVID-19 and SARS-CoV-2. The establishment of the effort and connections across Europe to national-level initiatives has been supported through uplifts to the Horizon 2020 ELIXIR-CONVERGE and EOSC-Life projects resulting in the development of a set of services that include databases, analysis tools and workflows, resources to make COVID-19 data 'FAIR' and significant computing resources. At the European policy level, both the ERA Versus Corona Action Plan[5], and the HERA Incubator[6] programme have placed the European COVID-19 Data Platform at the centre of research data sharing efforts. The new HERA Incubator programme will indeed support the expansion of the COVID-19 Data Platform enabling Europe and scientists globally to respond better to other future pandemics and outbreaks of infectious disease as and when they occur.

Imaging technologies provided by **Euro-BioImaging ERIC** are powerful tools to study any infectious disease agent that might cause emergencies such as COVID-19 did. They are of key importance for studies on the structure and function of pathogens at the cellular level, to understand virus infection, binding, intracellular trafficking, replication, assembly, etc. They are also crucial in revealing how viruses affect the host cell physiology and how the virus-mediated disease condition may be targeted by drugs or other interventions. Imaging-related services are also needed in the discovery and development of new vaccines and virus-targeted drugs, e.g. imaging of immune cells to reveal binding of antibody components to viruses or viral replication inside the host cell. In the clinical field, PET-CT technologies allow imaging of the biodistribution of vaccines after administration. Image data services built on artificial intelligence and machine learning applications address the complexity of virus-mediated disease analysis, especially when combining advanced imaging data with cohort data and other large biomolecular datasets.

Structural biology technologies provided by **INSTRUCT ERIC** are central to the pharmaceutical field, in particular to determine the 3D structures of druggable proteins – and thus determine sites where small molecules might bind – or to characterize viral protein antigens or specific parts of them to unravel their interactions with human antibodies. Indeed, these technologies properly integrated produced the structural characterization of key proteins only weeks after the SARS-CoV-2 sequence was released. INSTRUCT ERIC X-ray, Cryo-EM and NMR centres have brought these technologies centre-stage in drug discovery and since then there is a strong commitment to prioritizing COVID-19 researches. INSTRUCT ERIC established also a Resource Centre with tools and information to assist research relating to SARS-CoV-2 and COVID-19.

2. Life Sciences Research Infrastructures (LS RIs)
https://lifescience-ri.eu/ls-ri-response-to-Covid-19.html

3. RIs against COVID-19 pandemic
www.esfri.eu/Covid-19

4. COVID-19 Data Portal
https://www.Covid19dataportal.org/

5. ERA Versus Corona Action Plan
https://ec.europa.eu/info/sites/default/files/covid-firsteravscorona_actions.pdf

6. HERA Incubator
https://ec.europa.eu/info/news/eu-invest-eu150-million-research-counter-coronavirus-variants-2021-feb-17_en

INFRAFRONTIER rapidly evolved a broad portfolio of services to evaluate the potential of new anti-COVID-19 compounds and therapeutics on suitable humanized models as well as BSL3 laboratories for *in vivo* testing, through which the compounds can proceed to clinical testing. INFRAFRONTIER has also launched a new service call to provide researchers access to test their innovative and novel COVID-19 therapeutics in a standardized infection pipeline that uses preclinical models developed to study COVID-19 infection and its pathophysiological consequences, including the complete characterization of genes critically involved in the infection and the effect of the new anti-viral compounds.

Drug repurposing activities and high-throughput screening assays services made available by **EU-OPENSCREEN ERIC** are key to identify candidate molecules for COVID-19 therapeutics and, to this end, a collection of about 2,500 bioactive molecules from EU-OPENSCREEN was tested. All chemical and biological data are made available in EU-OPENSCREEN open access *European Chemical Biology Database*[7] and the European COVID-19 Data Platform[4]. The EU-OPENSCREEN ERIC collection of about 1,000 fragments was used to identify novel binders to Nsp3, an essential component of the replication complex of the virus. Data for 24 compounds from the collection provided alternative starting points for the development of anti-COVID-19 therapeutics.

EATRIS ERIC provided to COVID-19 vaccine developers the *EATRIS COVID-19* Research Forum, quickly made publicly available and updated weekly, developed a self-test, which reached wide media coverage[8] and is working to develop and introduce to the market a nasal spray vaccine against COVID-19[9].

ECRIN ERIC rapidly provided informatics services to harvest information on any COVID-19 actions in the biomedical fields. Within the EOSC-Life project, ECRIN developed a secure and GDPR-compliant patient-level data pilot repository linked to the EU COVID-19 data portal, enabling COVID-19 trial data sharing, while participating in the VACCELERATE project[10] is contributing to the activities for future pandemic preparedness (HERA Incubator).

Specific role in the infection threads plays **ERINHA**, a pan-European Research Infrastructure dedicated to the study of high-consequence emerging and re-emerging pathogens. ERINHA offers access to a large range of high containment *in vitro* and *in vivo* capacities to facilitate a wide variety of studies on SARS-CoV-2/COVID-19 and coordinates joint RI European activities regarding the service to vanquish COVID-19 pandemics.

Besides RIs in Life Sciences, also other RIs provided specific services during the COVID-19 crisis.

According to UNESCO[11], the ocean can be an ally against COVID-19. Bacteria found in the deep sea are used to carry out rapid testing to detect the presence of COVID-19. Species found in the ocean offer an excellent promising future for pharmaceuticals. Years ago, research from the Woods Hole Oceanographic Institute identified microbes living in deep-sea hydrothermal vents harbour whose enzymes can be used in diagnostic tests, like those to detect the pandemics of AIDS and SARS. Their role has been revisited for COVID-19; they have been used to carry out rapid tests to detect the virus's presence. **EMSO ERIC** ecology and biodiversity services include developing samplers with other ERICs – **EMBRC ERIC**, **LifeWatch ERIC** – for DNA monitoring.

ACTRIS supported the authorities by securing the full documentation of atmospheric composition changes due to lockdowns in the various parts of Europe. The main goals were: i) to provide reliable estimates of effects of reduced emissions; ii) to open some atmospheric simulation chambers for testing protection gears such as face masks; iii) to support authorities by providing science-based analysis of current knowledge and finally; iv) to illustrate the complex interplay between emission restrictions and human behaviour, and the necessity for structural changes to reach the WHO air quality standards in Europe.

FAIR at GSI efforts have been providing new insights and new technologies that may help to fight the SARS-CoV-2 virus: i) ion radiation for vaccine development; ii) therapeutic effect of low-dose radiation in SARS-CoV-2 induced pneumonia; iii) Improved and fast virus detection with single nanopore membranes.

The biology laboratories of **European XFEL** joined DESY and its partners in the screening effort to find novel binding partners to inhibit two important SARS-CoV-2 proteins (main protease and papain-like protease) using drugs that are either already on the market for other diseases or in late clinical trials. In parallel, EuXFEL contributed to the international effort on COVID-19 research by preparing and supporting a variety of Covid-related experiments, utilizing liquid jet serial femtosecond X-ray crystallography (SFX) to investigate new structures and time-resolved SFX of COVID-19 proteins.

The particular contrast provided by neutron techniques by ILL helps scientists to determine how protein complexes function, as well as the specificity of protein interactions with membranes. Finally, neutron spectroscopy provides insight into the dynamics of the biological components, which may constitute the ultimate key to understanding their functionality.

SKAO played an active role in the COVID-19 pandemic response, with contributions spanning from managing the design and production of respiratory ventilators and 3D printing of Personal Protective Equipment to the development of educational online tools

7. European Chemical Biology Database
https://ecbd.eu

8. Gargling test: Czech Republic trials faster & cheaper way to check for coronavirus
https://www.youtube.com/watch?v=oOn3sQP92lg

9. University of Eastern Finland researchers introduce a nasal COVID-19 vaccine – Science Business, March 2021
https://sciencebusiness.net/network-updates/university-eastern-finland-researchers-introduce-nasal-Covid-19-vaccine

10. VACCELERATE project
https://www.vaccelerate.eu

11. COVID-19: the ocean, an ally against the virus
https://en.unesco.org/news/covid-19-ocean-ally-against-virus

to support home-schooling or contributing to a public information campaign to combat misinformation, just to mention a few.

Feasibility studies in the **ESRF Extremely Brilliant Source**, the world's first high-energy fourth-generation synchrotron, have already demonstrated it can resolve unprecedented detail revealing the damage caused by COVID-19 on human lungs, linking from the major airways all the way down to the finest micro-vasculature in an intact lung. promises to develop a transformational X-ray tomography technology that will enable the scanning of a whole human body with resolution of 25 microns, thinner than a human hair – tens of times the resolution of a CT scanner. Further, it can then zoom into local areas with cellular-level imaging, or one micron – over 100x better resolution than a CT scanner.

PRACE has made computing time available at short notice throughout Europe for projects in connection with COVID-19[12]. Thirty different projects ranging from molecular biology to epidemiology were computed.

Also, RIs in the Social Sciences domain acted promptly to assess the impact of the pandemic on the society at large. A special Corona questionnaire included in the **SHARE ERIC** targeted telephone interviews (Computer-Assisted-Telephone-Interview, CATI) from June to August 2020, brought to release the Wave 8 COVID-19 data in December 2020, available for researchers all over the world to examine the health, social, economic and environmental situation of European citizens and beyond against the background of the pandemic. A further wave of telephone interviews of the SHARE Corona survey has been conducted in 2021. This study is the ideal database to study the non-intended socio-economic and health consequences of the epidemiological containment decisions and the long-term effects of the COVID-19 pandemic.

In its 2020-2021 round, the **European Social Survey ERIC** added a dedicated COVID-19 module to its longitudinal questionnaire including a number of health indicators. Combined with its core questionnaire, the dataset will enable ample opportunities for pre-post analyses of the wider social, economic and political consequences of the SARS-CoV-2 pandemic, for examining the medium and long term effects of the pandemic across countries and social groups, and for comparing policy responses and their outcomes in terms of social inequalities and social cohesion. At the same time the pandemic highlighted the fragility of relying on face to face fieldwork for RIs like the ESS. An alternative method has been developed to ensure data collection in 2021 can proceed. The need for a permanent panel infrastructure, reaching respondents by web and other non in-person methods, was underlined.

In June 2020 **DARIAH ERIC** launched a call under its bi-annual DARIAH Theme funding scheme entitled 'Arts, Humanities and COVID-19'. Projects being submitted to this call are being asked to explore how DARIAH ERIC will collect, curate, preserve and interpret the heterogeneous record of the experience of life and work in early 2020. DARIAH will also look for innovative projects exploring humanities contributions to understanding the virus and its impacts, and what the study of culture, the arts, values, practices and language can contribute to our response to this global challenge.

Through extending the collection of parliamentary datasets with curated collections of recent parliamentary debates about the corona dynamics, the European Research Infrastructure for language resources **CLARIN ERIC** set the basis for comparative research into how public bodies have responded to the crisis across countries.

The COVID-19 pandemic has demonstrated the capacity of the ESFRI RIs to respond to emergencies providing specific services to support the science-led response to the COVID-19 outbreak and also the capacity in many cases to rapidly react and return to operate even during the lockdown period. The Covid crisis has massively accelerated some pre-existing trends, in particular digitalization. It has shaken the world, setting in motion a wide range of possible trajectories.

Perhaps the most important lesson learnt is that the ESFRI RIs ensure that research across all topics and areas can continue even during a big crisis. Not knowing where the next crisis may hit, the ESFRI RIs are preparing their research programme along all fronts including fundamental research trying to be ready to provide the necessary services to society.

12. PRACE Versus COVID-19: Actions & Activities
https://prace-ri.eu/hpc-access/hpcvsvirus/

ESFRI RIs FOR DIGITAL TRANSFORMATION

The digital transformation of Europe's economies and societies is accelerating. It is entering a next phase, where the technologies are gradually blurring the limits between the physical, digital and biological spheres and push the frontier of what computers are capable to do. These new technologies, progressively coming to maturity and impacting all sectors of our lives and of the economy, build on the use of data, and often require the critical mass of data, users and connected nodes to be viable.

ESFRI is an active actor of this European dynamics. As it was stated already in the ESFRI Roadmap 2018 (page 117), the pan-European e-Infrastructures for Networking, High-Performance Computing and High-Throughput Computing are already well-established and provide production services used by international research and Research Infrastructures projects.

The fundamental principles of Open Science form the basis of the European Open Science Cloud (EOSC) initiative which will offer researchers a virtual environment with open and seamless services for storage, management, analysis and re-use of research data, across borders and scientific disciplines by federating existing data infrastructures. EOSC will deploy a European Research Data Commons where data are findable, accessible, interoperable and reusable (FAIR), and also as open as possible.

CONTRIBUTION TO EOSC

All the ESFRI RIs are at the forefront of data science. As providers of thematic quality data and services, which are FAIR compliant or are working to reach this objective, they have been making significant contributions to the cultural change towards open/FAIR data, open science and innovation, which is a main underlying concept for EOSC. On the other hand, RIs and their communities as key consumers/users of EOSC data and services within and across scientific domains, they are central for EOSC development, quality and sustainability. The broader the federation of thematic RIs in EOSC and the uptake of EOSC generic (horizontal) services, the better the chances for EOSC to be sustained in the longer term. Research Infrastructures are thus central in the research lifecycle and in all the aspects of Open Science and FAIR data/services inside the European Research and Innovation Area.

These activities are supported at EU level within the EOSC cluster projects which support also their participation and inputs to the development of the European Open Science Cloud. There are five thematic cluster projects – ENVRI-FAIR, EOSC-Life, ESCAPE, PaNOSC, SSHOC – who coordinate their actions towards EOSC and who are core partners in the EOSC Future project. It will integrate the services developed in the cluster projects to EOSC, making them fully compatible and accessible to the entire EOSC eco-system. The five science clusters bring together 72 world-class Research Infrastructures from the ESFRI Roadmap and beyond. The coordinators of the science cluster projects meet regularly to discuss joint activities, exchange views on technology choices and debate how the outputs from the projects can be best sustained once the projects end. The current dynamic between the science clusters may lead to a long-term collaboration for cross-disciplinary open science.

It is therefore a great opportunity and in the benefit of all stakeholders, including ESFRI RIs, thematic clusters and EOSC to make the most out of this venture. The experience gathered by ESFRI, ESFRI RIs and the ESFRI Clusters should be utilized to the maximum extent in the EOSC implementation, especially in this current second phase, fully reflecting the engagement and responsibility of RIs in and for Open Science. EOSC highlights the potential of the RIs with their data, software and services and their broader potential impacts. The RIs participation in the development of the EOSC are therefore a particularly vivid example to the digital transformation in the research and innovation field.

OPEN SCIENCE

Most of the RIs on the ESFRI Roadmap are at the forefront of Open Science movement and make important contributions to the digital transformation by transforming the whole research process according to the Open Science paradigm. The Research Infrastructures guarantee the quality of data and enable the exploration and use of data and codes produced by their users which can be the source of a new approach to the research questions, or at least lead to a reduction in research times and costs. There exist although differences in the concrete implementation of Open Science by Research Infrastructures. These differences are specific to each scientific field. The methods of producing research data are very different depending on the field of research and may have developed before the concept of Open Science was adopted.

Astronomy has a long history of open sharing of data and scientific findings, allowing a cumulative development of knowledge about our Cosmos and supporting the achievement of the conditions for transparency and international cooperation in science. In the modern era, astronomy is at the forefront of digitalisation for Open Science. ESO was early leader in this regard, establishing an open-access ESO Science Archive and setting up cooperative partnerships with other Research Infrastructures to ensure interoperability.

CTA is working to build an EOSC for astronomy, Astroparticle & Particle Physics and its application for science projects, including also a science analysis platform where the science community can access and combine data and analysis software from multiple ESFRIs and stage it for innovate analysis workflows, e.g. to perform multi-messenger analysis and push the digital transformation. Open science, and specifically the ability to find, access, inter-operate, re-use both **SKAO** data and software, is at the heart of SKAO's software development culture and practices. The scientific return of a project at the scale of SKAO will only be maximised if the data products can be accessed by future users, to answer as yet unforeseen questions.

All the RIs from the environmental research field have a long tradition in providing open access to data. In particular, **ACTRIS**, **IAGOS**, **ICOS ERIC** and **EURO-ARGO ERIC** contribute with their data products to Copernicus, the European Union's Earth observation programme, which provides open data and services to benefit all European citizens.

EPOS ERIC provides: (a) a portal (Integrated Core Services-Central hub, ICS-C) integrating FAIRly digital assets from ~250 asset suppliers; (b) an appropriate governance, legal and financial framework tackling long-term sustainability to secure the assets and the ICS-C; (c) a suitable approach for sharing best practices among data providers, domain-specific geoscience organizations and EPOS ERIC. In EPOS assets represent data, scientific products, services and software for solid Earth science. The EPOS federated approach is aimed at engaging national and international Research Infrastructures to share data, making them accessible and usable.

In the health domain **ECRIN ERIC** has developed tools and services to optimise data management in clinical research. ECRIN developed a data centre certification programme based on about 100 criteria and 3-days site audits to ensure compliance with GCP, FDA and EU regulations. About 15 centres are currently certified in Europe, and the certification programme is now going global, with certified centres in Asia (two in Japan, one in Korea).

In the Social Sciences the principle of open science especially in relation to data access has been strong for many decades. The **European Social Survey ERIC** for example makes all of its data freely available without privileged access for non-commercial use around the world and has over 160,000 registered data users.

BIG DATA VOLUME

Research Infrastructures constitute a central actor for the production or processing of research data because the majority of them produce, manipulate, process and/or exchange data. The massive growth in demand for computing resources in recent years calls for a coherent and ambitious strategy at the levels of infrastructure capacity (networks, computing and processing, storage and archiving capacities), associated services, and more generally a rethinking of the place of research data.

User experiments at the **European XFEL** generate vast amounts of data in a very short period of time. The maximum burst data rate per scientific instrument that must be captured is currently 8 TB/s and translates, when operating scientific instruments in parallel, to a sustained data rate of over 40 GB/s. For a typical user experiment running over 6 days, this can lead to user datasets in excess of 1 PB. Together with the scientific user community, European XFEL is developing computational methods to efficiently analyse the data, both in real time and on the subsequently recorded data to derive meaningful scientific results.

The **HL-LHC** project presents unprecedented challenges in terms of data processing and storage. CERN operates a number of FAIR data related services that represent major contributions to EOSC, including access to petabytes of LHC experiments' data together with associated training material and software via the CERN Open Data Portal[13] according to a published open data policy[14].

An important activity is currently being kicked off in **ESRF** for developing data compression algorithms. This is of high interest to all photon sources because all of them are confronted with a steady increase of the data produced by fast high-resolution detectors.

In the health scientific domain, over the last

13. CERN Open Data Portal
http://opendata.cern.ch/

14. CERN Open Data Policy for the LHC Experiments
http://opendata.cern.ch/docs/cern-open-data-policy-for-lhc-experiments

decades, advances in technologies such as genome sequencing and mass spectrometry have resulted in ever larger volumes of valuable research data being generated. The computational biology enabled through this has transformed our understanding of life at all levels and forms. **ELIXIR** is a distributed, virtual infrastructure where users access online the many hundreds of digital services that are run by ELIXIR Nodes. These include databases, software tools, computing services, interoperability resources and standards, and training in how to use those.

Moreover, new methods in bioimage informatics, including machine-learning approaches and artificial intelligence, are developing at breath-taking speed, opening new and exciting possibilities to fully exploit FAIR image data for life scientists and beyond. Currently, biomedical and life science researchers produce large-scale image data and, therefore, have acute needs for advanced image data analysis and imaging bioinformatics. However, these researchers are often equipped with limited computational resources and basic informatics skills. Consequently, they are not yet enabled to implement and use complex analysis workflows or to make their image data FAIR.

Euro-BioImaging ERIC is working to change this. Through Euro-BioImaging, users already can archive their image data and have access to community-accessible tools for image analysis and processing that can be used via the cloud (as part of EOSC-Life). Euro-BioImaging aims to fuel the new discipline of imaging bioinformatics and to integrate data research across different scientific domains to address larger questions and key societal challenges, e.g. health and ageing, climate change, and food security.

RIs in the Environmental domain produce vast amounts of data with on average a good level of Fairness. However, to study complex phenomena as the Earth System or the Climate System there is a need to increase High-Performance computing resources.

In data-intensive industries access to very large volumes of high-quality data is of primary importance. The most important tech companies are not based in Europe, consequently their activities aimed at acquiring huge amounts of data do not always meet European standards, especially when it comes to privacy and data protection. **CLARIN ERIC** offers a more sustainable alternative, emphasising the quality of data (which are accompanied with metadata and annotations) over the quantity. CLARIN data and tools can be used to develop, train and evaluate many language-related data-intensive technologies, such as Machine Translation, Automatic Text Simplification or Automatic Text Summarisation, Automatic Text Generation, Knowledge Extraction or Machine Learning. The multilingual and multimodal character of the data and resources available through CLARIN promotes a culture of global citizenship and appreciation of cultural diversity, which is also another contribution to shaping digital transformation in alignment with Europe's values.

DIGITAL INNOVATION

The European Strategy of shaping Europe's digital future can strongly be supported by large-scale RIs that have already proven to be an excellent environment for creating digital innovations. The associated cutting-edge research is always driven by novel technological opportunities, including digital technologies. Big Data, Data Processing and Analysis, Data access, High Data Rates, Modern Computing technologies are nowadays extremely important to face many global challenges (climate, environment, health, including the COVID-19). These are indeed common RI tools which are constantly evolving towards innovations on the grounds of RIs. A great example of very recent innovations in the field of digital technologies for competitiveness and fit for the Green Deal is a direct spin-off of the FAIR project, an innovative energy-efficient and sustainable data center called Green IT Cube which is currently one of the most efficient scientific computing centers in the world, using an innovative patented water cooling system of the racks and making it thus a great example of the digital sector's policy to minimize carbon emission.

As a major analytical research facility, the **ILL** relies heavily on IT infrastructure to convert its experimental output into scientific knowledge. In this context, digital transformation holds the promise of major disruptive innovation. Machine learning can be applied to the recognition of patterns within the experimental data, making it possible to optimise the measurement strategy and fine-tune instrument parameters during operation and development. The **ESRF** has started an ambitious programme to work on machine learning methods. Machine learning is of importance for reducing noise in the data, automatically detect patterns which otherwise would go unnoticed, and for optimizing experimental conditions allowing to shorten the time required for the data acquisition process.

ACTRIS provides access to users to Virtual Research Environment to conduct specific experiments, simulations, and online data processing. **LifeWatch ERIC** seeks to understand the complex interactions between species and the environment, taking advantage of High-Performance, Grid and

Big Data computing systems, and the development of advanced modelling tools to implement management measures aimed at preserving life on Earth.

ELIXIR activities are at the heart of the digital transformation of life science research. ELIXIR connects, coordinates and integrates bioinformatics resources across Europe, building a coherent life science infrastructure for the digital age and supporting everything from expert bioinformaticians to life science generalists and users from academia to industry.

Digital transformation is also a cornerstone of personalised medicine. In this context **EATRIS ERIC** and **ECRIN ERIC** are developing methodological standards which include the generation, through stratification cohorts, of multi-omic data with subsequent machine-learning stratification to identify homogeneous patient clusters, then clinical trials will test treatment options driven by this complex profiling.

DARIAH ERIC mission is to empower research communities with digital methods to create, connect and share knowledge about culture and society. Its distributed structure is optimally constructed to support digital transformation across its network.

In its 2021 round, the **European Social Survey ERIC** is including a special module on 'digital social contacts at work and in family life'. The module will include items on opportunities for access to digital communication (e.g. Internet access at home), the need for them (e.g. lower co-residence) and trust in digital social contact (e.g. privacy concerns), as complements to questions on workplace culture and available country information (e.g. on work related state policies). These are likely to shape individual agency to establish digital social contact in a way that it facilitates work-life balance and encourages relationship quality or well-being. The ESS is also building infrastructure for an on-line panel of the future with the hope to link a representative sample in a digitally designed Research Infrastructure of the future.