RINGO | Readiness of ICOS

READINESS OF ICOS FOR NECESSITIES OF INTEGRATED GLOBAL OBSERVATIONS

Final RINGO project report

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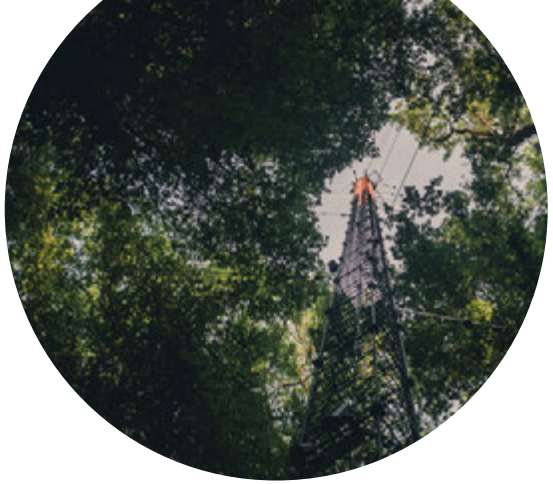
Contents



1 Introduction

The overall goal of the European Commission's Development and long-term sustainability of new pan-European research infrastructures (INFRADEV-03-2016-2017) call was to provide Europe with a comprehensive landscape of sustainable research infrastructures that would help to respond to challenges in science, industry and society. The call targeted research infrastructures in the most challenging phase in their life cycle: in the process of becoming fully operational and financially sustainable.

RINGO, '**R**eadiness of **I**COS for **N**ecessities of **I**ntegrated **G**lobal **O**bservations' (2017–2020) has been a four-year European Union's Horizon 2020 project to support the further development of the Integrated Carbon Observation System (ICOS), a Landmark Research Infrastructure in the European Strategy Forum on Research Infrastructures (ESFRI) roadmap.

ICOS provides data and knowledge on greenhouse gas (GHG) budgets and their perturbations. Its core activities are long-term observations in the atmosphere, within ecosystems and on the oceans. Observations are required for understanding the present state and for predicting the future behaviour of the global carbon cycle and GHG fluxes. ICOS promotes technological developments and implementations, related to GHG observations, by linking together research, education and innovation.

> *"ICOS is a distributed research infrastructure operating standardised, high-precision, and long-term observations, facilitating research to understand the carbon cycle, providing necessary information on greenhouse gases. ICOS-based knowledge supports policy- and decision-making to combat climate change and its impacts. ICOS is the European pillar of a global GHG observation system. It promotes technological developments and demonstrations related to GHGs by the linking of research, education and innovation."*
>
> *ICOS Mission Statement*

The RINGO project further developed the readiness of the ICOS research infrastructure (RI) to meet these challenges. It has to be noted that the term 'readiness', as defined in the RINGO concept in 2016, is slightly different from the recently introduced concept describing the life cycle of an RI by 'readiness levels' in the report Supporting the Transformative Impact of Research Infrastructures on European Research *(European Commission 2020)*. However, since the report reflects the efficiency of the European Union (EU) funding for the development of research infrastructures, it is frequently cited in RINGO's Work Package descriptions.

The objectives described on the right defined the Work Package (WP) structure of the project. The objectives have not been isolated but strongly interconnected. This report will reflect the impact of the RINGO project on the development of ICOS and describes the main results achieved.

RINGO had five objectives related to readiness:

SCIENTIFIC READINESS. To support the further consolidation of the observational networks and enhance their quality. This objective is mainly science-guided and will increase the readiness of ICOS RI to be the European pillar in a global observation system on greenhouse gases.

GEOGRAPHICAL READINESS. To enhance ICOS membership and sustainability by supporting interested countries in building a national consortium, to promote ICOS towards national stakeholders, to receive consultancy e.g. on possibilities to use the EU structural fund to build the infrastructure for ICOS observations, and to receive training to improve the readiness of the scientists to work within ICOS.

TECHNOLOGICAL READINESS. To further develop and standardise technologies for greenhouse gas observations necessary to foster new knowledge demands, and to account for and contribute to technological advances.

DATA READINESS. To improve data streams towards different user groups, and to adapt to the developing and dynamic (web) standards.

POLITICAL AND ADMINISTRATIVE READINESS. To deepen the global cooperation of observational infrastructures and with that, the societal impact of ICOS RI.

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The Work Packages and their results

WORK PACKAGE 1:
INCREASING THE IMPACT OF ICOS

The Work Package 1 included several tasks to strengthen the scientific background of the ICOS network. WP1 advanced the observation networks of ICOS by improving sampling and measurement strategies for (i) monitoring fossil fuel carbon dioxide (CO_2) and verification of its emission inventories, (ii) analysing supplementary and stable isotope tracers on flask samples for CO_2 and methane (CH_4) source apportionment, (iii) budgeting lateral carbon and GHGs fluxes via rivers, streams estuaries and ocean, and (iv) non-destructive biomass estimates. The work carried out in WP1 bridged existing ground-based ICOS observations to satellite data via (i) vertical GHGs profiling of Total Column Carbon Observing Network (TCCON), (ii) space-based air–sea gas exchange parameters and (iii) using ICOS ground-truth information and Light Detection and Ranging (LiDAR) for validation of biomass parameters through space-based imaging.

ICOS is in a permanent process of optimising its networks, keeping it a front-runner in its field. The process has been supported by RINGO by improving the scientific readiness of ICOS for meeting future challenges in European and global GHG budgeting, including top-down verification of the 2015 United Nations Climate Change Conference (COP21) commitments.

Task 1.1, observable through Deliverable 1.1, focused – in addition to scientific achievements – on the organisational development of ICOS. It supported a strategic process that reflected on the purpose of ICOS RI. The process started an analysis on the socio-economic impact of ICOS, and continued to formulate a concise strategy that supported the smooth transition into the second five-year financial phase of the ICOS European Research Infrastructure Consortium (ERIC) and its financial sustainability. It formed the basis for the successful implementation of the first scientific evaluation of the entire RI. The task enabled the development of both key impact- and performance indicators to evaluate and monitor the progress of ICOS.

The scientific results are publicly available as deliverable (D) reports:

- D1.1 Strategy document on increasing impact of ICOS including a recommendation to ESFRI for comprehensive impact analyses for environmental RIs
- D1.2 Scientific-technical concept for requirements of a fossil fuel observation system including possible role of ICOS and resulting costs to be presented to EC, ESFRI and ICOS General Assembly
- D1.3 An ICOS flask sampling protocol based on historical time series and high resolution footprint modelling
- D1.4 Report describing the ideal and minimum requirements of an aquatic transport and fluxes observation system
- D1.5 Scientific-technical Concept for the integration of European TCCON sites into ICOS and resulting costs
- D1.6 Ocean-atmosphere flux NRT data calculation routine including satellite data streams on surface temperature, skin effects, wave state and wind speeds
- D1.7 Revised scientific-technical protocol for standardized biomass observations in ICOS by means of ground Lidar (M42)

WORK PACKAGE 2:
ENHANCING ICOS MEMBERSHIP AND SUSTAINABILITY

At the time of the RINGO project, ICOS RI had already been recognised as having an increasing role in scientific support for climate policy *(European Commission 2020)*. However, the geographical coverage of the networks and the long-term sustainability of ICOS depends to a large extent on the membership and the engagement of the member states. Thus, the core aspect of the WP2 has been to motivate more countries to become members of ICOS. It has supported the interested countries in building a national consortium, promoted ICOS towards national stakeholders, advised on possibilities to use EU structural funds to build the infrastructure for ICOS observations, and organised training to improve the readiness of the scientists to work within ICOS.

WP2 has fostered the capacity building in research infrastructure management, related scientific knowledge and research infrastructure human capital development in relevant regions. The work carried out in WP2 has increased the geographical coverage of the ICOS observations, for example during the past year, by helping Spain and Hungary to join ICOS RI and by training new ICOS member countries to be fully in line with the technical and scientific standards of ICOS.

While targeting mainly new members, WP2 also provided relevant information on best practices within the established ICOS community via training and sharing of expert knowledge. For example, the ICOS Handbook has received lots of positive feedback from ICOS Principal Investigators (PIs) who continuously onboard new staff and train the next generation of ICOS operators. This clearly shows the relevance of RINGO for the sustainability of ICOS. The ICOS training tradition has also been noticed by high-level expert panels outside ICOS community: "ICOS is organising internal training events for scientists and technicians; it also participated in several summer schools to train early-career scientists to use ICOS data" *(European Commission 2020)*.

The supporting material developed in WP2 is publicly available as deliverable reports:

- D2.1 Report on enhancing membership strategy for ICOS ERIC including the online Handbook for Stakeholders
- D2.2. Concept document on collaboration with countries and stations outside European Union
- D2.3 Initial joint training (including gender issues related training) for research infrastructure managers (PIs) and other relevant stakeholders of the ICOS candidate countries (M18) and tailor-made trainings for the ICOS candidate countries throughout the project duration focused on important managerial and funding issues connected with the ICOS research infrastructure establishment and membership
- D2.4 Online platform as part of ICOS webpages including technical and scientific training material
- D2.5 Organisation of at least three training workshops and summer schools for the ICOS candidate representatives and other participants oriented on the scientific content related to the ICOS research infrastructure establishment and operation

WORK PACKAGE 3:
TECHNICAL DEVELOPMENTS

A core aspect of ICOS – already developed and applied in the ICOS Preparatory Phase project (EU's Seventh Framework Programme, FP7) – is standardisation of measurements and compliance to the standards via certified station labelling. The WP3 was connected to this tradition and provided support to further develop and standardise technologies for greenhouse gas observations necessary to foster new knowledge demands, and to account for and contribute to technological advances. WP3 explored the technological necessities to enable the scientific concepts developed in WP1. It comprised technical pilot studies and workshop-based conceptual studies that have provided clear guidance for further technical innovations within ICOS. RINGO researchers cooperated internationally to provide comprehensive standards for observations on the Earth's climate system.

The developed in-situ observations made during the RINGO project facilitate the integration of ICOS measurements into the Copernicus Programme in the future. Thus, RINGO supported ICOS to succeed in the challenging position of reaching out "beyond any classical model of a research infrastructure since this activity will combine research with more agency-like monitoring" *(European Commission 2020)*.

The scientific results explained in the deliverable reports have improved the readiness of ICOS by providing a clear perspective of ICOS' technological readiness for stakeholders and funding organisations.

The technological specifications developed in WP3 are publicly available as deliverable reports:

- D 3.1 Specification for high accuracy in-situ vertical profile measurements including vertical profile retrievals of CH_4 from the ground-based TCCON
- D3.2 Report on implementation and technical realization of atmospheric measurements on the three VOS platforms (M20)
- D3.3 Technological Handbook and Assessment Report on Implementation of ATC-conform atmospheric measurements of CO_2 (and CH_4) on VOS lines
- D3.4 Technological Handbook and Assessment Report on CO_2-ASV
- D3.5 Protocol for non-CO_2 eddy covariance measurements, QA/QC, data processing and gap-filling
- D3.6 Proposition of a roadmap for enhancing ICOS Ecosystem sites to become sentinel sites in cooperation with other domain-specific ESFRI and global infrastructure

WORK PACKAGE 4:
IMPROVING DATA

RINGO improved data streams towards different user groups by adapting to the developing and dynamic (web) standards. The WP4 has increased the interoperability of ICOS data through a meta-data type registry. The findability of and the free access to ICOS data has been approved. Furthermore, legacy (pre-ICOS) data from ICOS stations were made available. These data were brought to the best possible level of quality, including data uncertainties, to enable long-term data analyses on trends. European Commission (2020) recognised as the most important innovation of ICOS to be the development of harmonised and standardised methodologies concerning open data. WP4 facilitated the completion of the data life cycle, resulting in the distribution of high-quality observations and open data flow to other synthesising projects (e.g. the Global Carbon Project) becoming easier.

The data-related achievements developed in WP4 are publicly available as deliverable reports:

- D4.1 ICOS data type-registry and unified meta-data base
- D4.2 Ambient CO_2 time series for the selected 10 measurement stations covering the period 2000-2015
- D4.3 Reprocessed long term data series from 9 ecosystem stations

WORK PACKAGE 5:
TOWARDS A GLOBAL CARBON AND GHG OBSERVATION SYSTEM

The work in the WP5 was closely connected to the ICOS-internal data improvements of WP4 by connecting them to international data efforts. ICOS cooperates internationally to provide comprehensive information on the Earth's climate system. WP5 has contributed to conceptualising a global carbon and GHG information system and developed the ICOS Ocean Thematic Centre towards becoming the European pillar of the Global Ocean Data Analysis Project (GLODAP) and the Surface Ocean Carbon Atlas (SOCAT), the ICOS Ecosystem Thematic Centre towards the European pillar of FLUXNET, as well as the ICOS Atmosphere Thematic Centre towards the European pillar of the World Data Centre for Greenhouse Gases (WDCGG). The work carried out in WP5 deepened the already existing global cooperation of observational infrastructures through the development of the scientific, technical and managerial processes, and contributed to the development of good practice guidelines in international cooperation.

The scientific results are publicly available as deliverable reports:

- D5.1 Concept for ICOS involvement in carbon and GHG flagship inside GEO and IG3IS program by WMO
- D5.2 GLODAP and SOCAT services fully implemented at OTC
- D5.3 Concept on data processing, management, and distribution in IG3IS and GEO flagship
- D5.4 Concept on standards for data collection, classification, description, processing and distribution and methods for data identification, traceability and sharing in FLUXNET
- D5.5 Increased data flows and improved mechanisms for data use tracking by improved data identification towards global data streams

WORK PACKAGE 6:
MANAGEMENT

The management work carried out in the WP6 played a pivotal role in monitoring the progress of the RINGO project, and also ensured its ongoing success. Furthermore, WP6 established good practices related to both project- and RI management and strengthened ICOS ERIC's ability to coordinate large, multi-beneficiary EU projects.

The management-related achievements developed in WP6 are publicly available as deliverable reports:

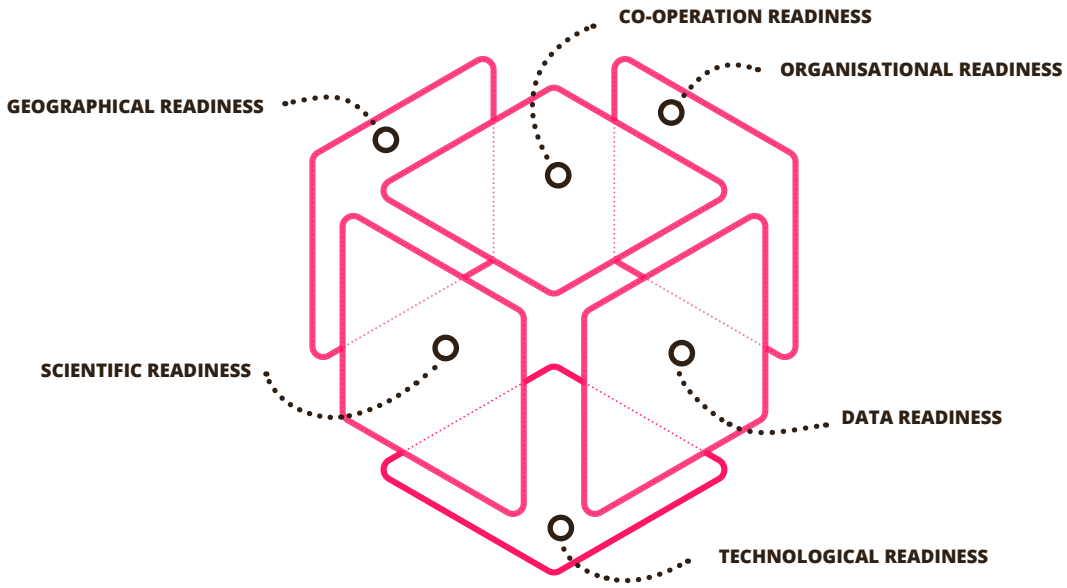
- D6.1 Organization of project Kick-off meeting, including a General Assembly meeting and Executive Board Meeting.pdf
- D6.2 Project Internal Communication.pdf
- D6.3 Initial Project Dissemination Strategy.pdf
- D6.4 Initial Data Management Plan.pdf
- D6.5 Initial Risk Management Plan.pdf
- D6.6 Updated Dissemination Plan.pdf
- D6.7 Updated Data Management Plan.pdf
- D6.8 Updated Risk Management Plan.pdf
- D6.9 Periodic Report 1 including request for first interim payment.pdf
- D6.10 Periodic Technical Report Part B.pdf
- D6.11 Final Dissemination Strategy.pdf
- D6.12 Final Data Management Plan.pdf
- D6.13 Final Risk Management Plan.pdf
- D6.14 Report to summarize the experiences of RIs with linked third parties in H2020 projects to the European Commission and the ESFRI.pdf
- D6.15 Report to summarize the experiences of usage of the KPI approach.pdf
- D6.16 Overview report of all annual meetings General Assembly and Executive Board meetings.pdf

3 Impact

The distinction between the impact of RINGO on ICOS and the impact of ICOS itself on science and society has been problematic ever since the proposal writing. This problem arose from the fact that each improvement of ICOS generated through RINGO achievements has also an 'impact on the impact' of ICOS. To fully grasp this 'impact cascade' remains a challenge, since the European Commission's call expected even more impact by defining some secondary goals, namely:

- strengthen the European Research Area (ERA) position and role in the global research environment
- reinforce the partnership between the European Commission, Member States, Associated Countries and relevant stakeholders in establishing pan-European research infrastructures
- enhance the role of the EU in international organisations and multilateral fora
- support progress towards the development of global research infrastructures
- enable researchers to address societal challenges with a global dimension
- foster capacity-building and research infrastructure human capital development in targeted/relevant regions

In this report, the described challenge will be solved by focussing on the direct impact of RINGO on ICOS in a first step and providing a brief analysis of the impact cascade in a second.



IMPACT OF THE RINGO PROJECT ON ICOS

During the years 2017–2020 ICOS has developed quickly. Many of the internal processes were fostered by the RINGO project. In the context of RINGO, the ability to further develop towards the desired directions was called by the project as 'readiness'. It included different definitions for above-mentioned dimensions of 'readiness'.

To better describe the impact of RINGO on ICOS, it is helpful to symbolise RINGO as a cube and take a closer look at each side of the cube that represent a different viewpoint of 'readiness'. This analysis starts with views on single aspects of readiness, and will thereafter take a two- or three-dimensional view to describe the synergies between different aspects, and finally, take a holistic view on the entire cube to see the integrated impact of RINGO on the sustainability of ICOS.

THE DIFFERENT DIMENSIONS OF READINESS ARE:

By being an ESFRI Landmark, ICOS is an important contribution to the European Research Area and part of the European portfolio of long-term undertakings in excellent science and innovation. …ICOS will thoroughly monitor, support scientific developments, and adapt to the demands of its scientific community. The ICOS science case has a primary focus on understanding carbon cycle feedbacks and possible tipping points." ICOS Strategy

RINGO has supported this strategic goal in manifold ways. The provided scientific-technical concepts (developed mainly in WP1 and WP3) required, in a first step, thorough scientific analyses or additional experiments. This has strengthened the science within and around ICOS. In addition, they can be seen as a good example for science being the base for societal action to mitigate climate change. The fossil fuel observation system scientifically conceptualised in Deliverable 1.2, as one example, has proven its reliability based on the scientific experiments

made in RINGO. It can now be further developed and applied in city observatories and can become part of the monitoring and verification support system for CO_2 and other GHGs envisaged by the EU.

TECHNOLOGICAL READINESS

ICOS also has a strong technological innovation potential to support excellent science on quantifying fossil fuel emissions from systematic in-situ observations." ICOS Strategy

The technological readiness is the next step in the innovation of the ICOS value chain, leading finally to data and services for climate action. Once the scientific background has been thoroughly explored, feasible technical solutions for standardised, high-precision observations become the next challenge for the implementation, mainly in WP3 and partly in WP1. RINGO has provided technical handbooks or measurement protocols for some core activities. They filled important gaps and will strengthen the quality of ICOS data products.

DATA READINESS

Through the access to high-quality, well-documented and traceable data documenting continuously the GHG cycle in the earth system, ICOS is about to become one of the main data providers for the entire biogeoscience community in this area." ICOS Strategy

The ICOS data life cycle needs readiness for optimising the internal data flow and the distribution of the data according to the Findable, Accessible, Interoperable, Re-usable (FAIR) principles. The ICOS-internal data flow has been facing a challenge that is probably occurring in many distributed research infrastructures that have been developed out of long-existing scientific communities: each domain has its own sophisticated metadata and data collection system, developed over the latest decennia, containing precious experience and expertise. In order to integrate them, exchange mechanisms and the internal standards to exchange and harmonise this metadata at the central repository have to be agreed on. The ICOS data type-registry and unified meta-database (Deliverable 4.1), where it is integrated as rich metadata into the ontology based triple store, is exposed to the users through machine-to-machine and user interfaces. Overall, RINGO strengthened the internal cooperation between ICOS Thematic Centres and ICOS Carbon Portal and increased the quality and efficiency of ICOS-internal data flows. It increased the findability and scientific usage of ICOS data and with that, the overall FAIRness of ICOS data. The easy access to ICOS data will boost elaborated data products that bridge between science and society and enable societal innovation related to climate change mitigation.

GEOGRAPHICAL READINESS

Network quality also includes geographical coverage and density of the networks. ICOS' remote strategic aim is to cover the full European continent with denser networks to reduce current uncertainties and to explore potential hotspots areas..." ICOS Strategy

Being well-distributed over the area of interest on one hand, and being an administrative entity where a membership in ICOS ERIC is a prerequisite for countries for integrating their

stations into the ICOS networks on the other, remains one of the largest challenges in the ESFRI model of organising RIs. RINGO has taken up this challenge with specific tasks (in WP2) to attract new countries and to broaden geographical coverage of its observational networks. In this context, the ICOS Handbook became an important tool to introduce ICOS to national stakeholders. The work towards geographical readiness, mainly in WP2, comprised nine candidate countries potentially joining ICOS. Two of the countries joined or will join ICOS: Spain by January 1st, 2021, and Hungary by January 1st, 2022. Several other countries may follow during near future. In addition, RINGO supported strategies for associate stations outside the EU / the ICOS member countries to join the network.

CO-OPERATION READINESS

The knowledge generated by the use of ICOS data supports efforts to comply with the Paris Agreement resolutions within the United Nations Framework Convention on Climate Change (UNFCCC). ICOS responds to the international goal of establishing global standards for observations as well as open, accessible, and interoperable data in order to ensure optimal services for societies in their efforts to mitigate climate change" ICOS Strategy

RINGO supported many ICOS activities at international level, mainly in WP5. ICOS Ocean Thematic Centre and ICOS Ecosystem Thematic Centre fostered important steps in the further implementation of the global data bases GLODAP and SOCAT in the Ocean domain, and FLUXNET in the Ecosystem domain.

ORGANISATIONAL READINESS

Organisational readiness was not explicitly mentioned in the proposal. Nevertheless, RINGO paved the way for ICOS into its long-term sustainability. When RINGO started in 2017, ICOS had had the ERIC status for about one year, and had just achieved the ESFRI Landmark status. However, the initial financial commitment of the member states was lasting only until the end of 2019. The process towards the long-term sustainability was to be organised, and the RINGO Task 1.1 was designed to support this process from the beginning. As part of this task, the ICOS Impact Assessment Report (2018) laid the foundation for an intense strategic discussion throughout all levels of ICOS RI. The resulting ICOS Strategy (2019) reinforced the partnership of all the stakeholders involved in ICOS by providing a very clear mission and a vision for its future development. The ICOS Handbook (the first edition published in 2019 and the second in 2020) provided a comprehensive description of all elements of the ICOS research infrastructure.

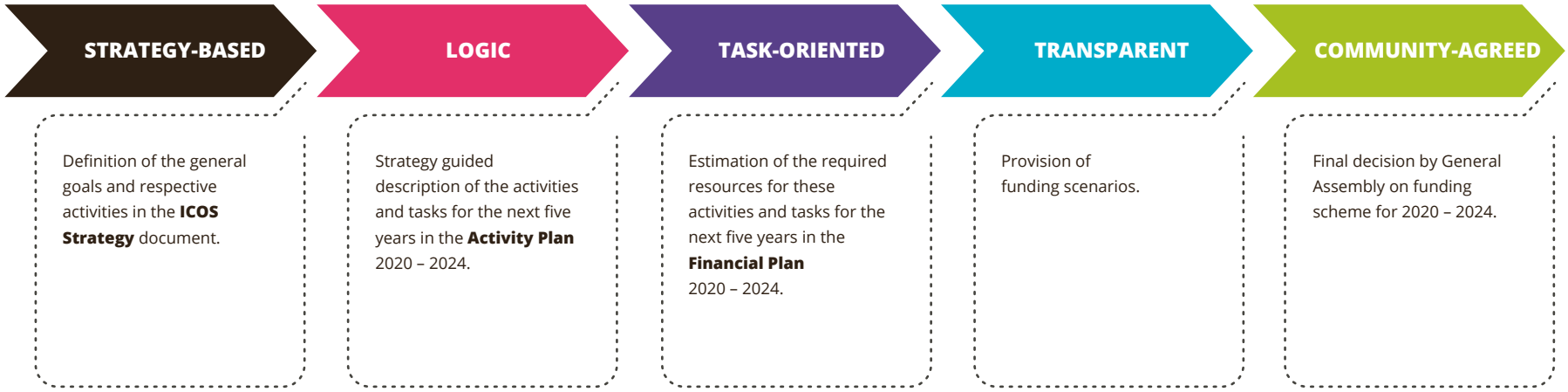
Based on these efforts, it was possible to present a five-year action plan for the second commitment period (2020–2024) to the ICOS General Assembly (GA) in May 2019. In November 2019, the ICOS GA decided on a funding scheme for the period of 2020–2024. All members and observers renewed their commitment to ICOS.

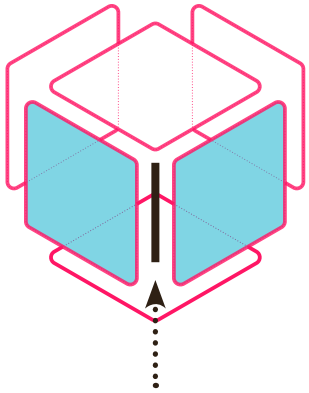
This improved administrate readiness of ICOS significantly already during the project and hence, made ICOS more desirable as a partner to coordinate future projects. The improved practices, for example when organising the international annual RINGO meetings, further improved the administrative readiness of ICOS. This impact is clearly visible in the ICOS Science Conferences.

At its present state, the political readiness of ICOS and its embedded societal impact provide continuous support to the UNFCCC. ICOS RI participates in the group on Earth observation, and actively supports the GEO initiative on Carbon and Greenhouse gases and the Integrated Global Greenhouse Gas Information System developed by the World Meteorological Organization.

ICOS standardisation is a basic element. It has required an international ICOS-like collaboration which brings together not only scientists, but also representatives of environment-related ministries. This has a cumulative unifying effect which is clearly visible on the governmental levels by means of science diplomacy. This unifying effect was recently noticed by the high-level expert group *(European Commission 2020)*, which recognised ICOS having an increasing role in scientific support of climate policy. The RINGO project not only facilitated, but also endorsed ICOS to reach its current status of which the ICOS community as a whole is truly grateful.

The following graph describes the crucial steps and most important milestones of this process – most of them either directly supported or impacted by RINGO.

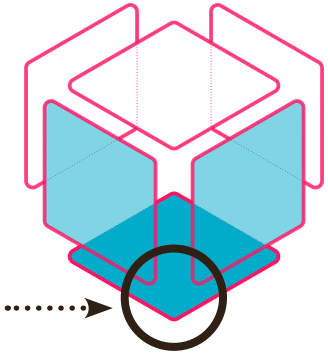




THE EDGE BETWEEN DATA AND SCIENTIFIC READINESS

Excellent science is best encouraged by providing easily accessible and high-quality data in a timely manner." ICOS Strategy

RINGO provided an excellent example of data readiness boosting science by providing consistent historical data sets. The original idea was to bring the historical data from ICOS stations as close as possible to the ICOS data quality, to enable better interpretation of current data using long-time series. However, the scope of this task was flexibly extended after the unprecedented severe drought episode occurred across Europe during spring and summer 2018. A task force analysed the impact of this extreme climatic event on the carbon cycle. To support this unique scientific opportunity, instead of processing historical data for only a handful of stations, an effort was made to collect all of the available data sets from Europe and provide a much larger data set enabling analyses of the year 2018 in its historical context. The drought initiative resulted in a special issue of the Philosophical Transactions of the Royal Society B with 17 scientific publications. Even though these publications might not mention the RINGO project in the acknowledgements, since the scientific work itself was not supported by the project, they can be seen as 'enabled by RINGO', since they were using data sets created in the RINGO framework.



THE CORNER BETWEEN SCIENTIFIC, TECHNOLOGICAL AND DATA READINESS

The ICOS Flask Sampling Protocol is an excellent example for demonstrating the multi-dimensional impact of RINGO on ICOS. The goal was to develop an optimal strategy for flask sampling with an automated sampler. Flask sampling is an important part of the ICOS Atmosphere station network and has three different purposes: (i) provide an independent quality control for in situ observations, (ii) provide representative information on components currently not monitored in situ at the stations, (iii) collect samples that are significantly influenced by fossil fuel CO_2 emission areas for radiocarbon dioxide ($^{14}CO_2$) analysis.

The funding by RINGO enabled a scientific study that has been based on improved data and modelling services by the ICOS Carbon Portal. By estimating the origin of the air masses arriving at an atmosphere tower at a certain time and using the continuous in situ CO observations, an algorithm was introduced to support the decision on whether a flask sample should be analysed for $^{14}CO_2$ or not. The resulting technological innovation will integrate the three purposes of the flask sampling and increase the information on fossil fuel CO_2 emissions in the area observed by the ICOS Atmosphere station network.

IMPACT ON THE COPERNICUS MVS SYSTEM AND THE EOSC

The RINGO project strongly impacted on larger European endeavours, namely the Copernicus Monitoring and Verification Support (MVS) capacity for CO_2 and the European Open Science Cloud (EOSC), by increasing the readiness of ICOS. Optimised observational technologies and data streams have enabled ICOS to play a pivotal role in the design and preparation of the MVS system. Synergies with projects such as the CO_2 Human Emissions (CHE), Verifying Greenhouse Gas Emissions (VERIFY) and Copernicus evolution – Research activities in support of a European operational monitoring support capacity for fossil fuel CO_2 emissions ($CoCO_2$) enabled ICOS to become a stable supporter of the MVS system.

The process of improving data readiness of ICOS within RINGO had strong synergies with Supporting environmental research with integrated solutions (ENVRIplus) and ENVironmental Research Infrastructures building Fair services Accessible for society, Innovation and Research (ENVRI-FAIR) cluster projects. Developing the data life cycle of one research infrastructure is an important base for common data solutions within a cluster of research infrastructures. RINGO enabled ICOS to share its experience within the Cluster of Environmental Research Infrastructures (ENVRI), particularly within the ENVRI-FAIR project. In the long run, ICOS and ENVRI will be enabled to play a key role in the further development of the EOSC.

GENERAL SOCIO-ECONOMIC IMPACT

General socio-economic impact is closely interlinked with the above-mentioned impacts. In addition to the reached goals, RINGO contributed to the development of ICOS' capacity for fast-tracking ICOS knowledge transfer (e.g. the study on the 2018 drought) as well as strengthened the ICOS community beyond the RI itself by fostering a co-creation culture – by bringing together ICOS infrastructure and non-ICOS partners and regional, national, EU and global stakeholders. The RINGO project has also contributed to ICOS' readiness for EU's Green Deal goals. ICOS is ready to coordinate the development of urban GHGs observatories hand in hand with a wide range of stakeholders, for example municipalities, regions, non-governmental organisations and civic societies, to further develop its policy briefing and general communication services on greenhouse gas emissions and the carbon cycle, and to provide high-precision and standardised data to support the mitigation of and adaptation to climate change.

SUMMARY ON THE IMPACT

The RINGO concept of 'readiness' has been more detailed than the criteria related to the six readiness levels in the EU report *(European Commission 2020), nevertheless comparable. Looking back and relating the efforts done in RINGO to the development of ICOS during its transition from the implementation and construction to the operational phase, it might be stated that during the time of the RINGO project ICOS developed from Readiness Level (RL) 4 to Level 5, and RINGO greatly impacted this development: "ICOS has reached operational stage and has a high potential to become a reference pan-European facility. It is currently assessed as being at RL5, and it will further progress towards RL6 within cluster projects" (European Commission 2020). This indicates that RINGO contributed significantly to the overall readiness and the long-term sustainability of ICOS.*

4

Monitoring the progress of ICOS and the impact of RINGO

During the project, it became clear that the utilisation of a key performance indicator (KPI) system for the sole purpose of monitoring the performance of a development project, such as RINGO, would be short-lived and would not bring added value in the long term. Experiences of using the KPI approach were discussed in detail in Deliverable 6.15. This report will take up two more general aspects related to monitoring of research infrastructures and the projects to support them.

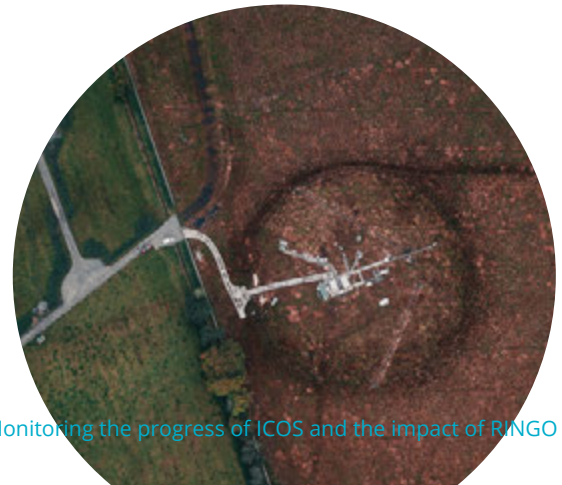
The first aspect relates to monitoring and evaluation of RIs in general: regular evaluations of ICOS are foreseen by the ICOS ERIC Statutes (Article 2) in response to the ERIC Regulation (Article 10). The challenge of the first evaluation was that no common assessment framework was available except for the ESFRI Working Group Report Monitoring of Research Infrastructures Performance, which turned out to be an important source for deriving KPIs, but was not easily applicable in all aspects of performance. This resulted in an iterative process between the ICOS GA, the Evaluation Committee, the different bodies of the ICOS research infrastructure and the ICOS Director General to develop an ICOS-specific evaluation framework that might also be a benchmark for other research infrastructures and an important input for the further progress of the ESFRI monitoring process. The work performed in Deliverable 1.1 was submitted to the Evaluation Committee and it turned out to be a very valuable input since the approach developed in the RINGO project provided the necessary holistic perspective: key performance indicators and key impact indicators have to be aligned with each other and with the overall strategy of ICOS. Finally, a set of 36 KPIs was developed and applied by the Evaluation Committee.

> *ICOS has been reviewed by an external, expert Evaluation Committee at the end of its five-year implementation period. The review was based on documentation and data provided by ICOS as well as surveys of a wide range of ICOS staff and stakeholders, and engagement in a two-day meeting between the Evaluation Committee and many of those surveyed. A set of key performance indicators (KPIs) were also established and evaluated, noting that some of them are particular to the implementation phase, and others will need to be developed further as ICOS develops. This is the first time that an evaluation has been held of such distributed research infrastructures, so the process and its outcome may be of interest to a wider range of RIs, their stakeholders and to policymakers. (Evaluation Report 2020)*

The evaluation was organised around five areas: management, financial management, internal engagement and integration, data and user expectations, and international cooperation.

In general, the Evaluation Committee found that ICOS completed its implementation phase very successfully, with a well-established governance as well as operational and financial management processes. It has made a significant progress in providing temporal and spatial data on greenhouse gases in Europe, all channeled robustly and efficiently through the ICOS Carbon Portal. Also, a high degree of integration was found across the different elements of ICOS. The outputs of ICOS in the form of data, publications, as well a scientific and outreach events have been rising strongly. ICOS has established itself as a global power in the GHG and climate change area through strong engagement with all key global organisations that influence international policy making. ICOS should now prepare to build on these achievements by developing policies, processes and activities in all the areas evaluated. The Evaluation Committee has identified specific areas for improvement and made specific recommendations on the possible means to monitor and assess progress in the main categories examined, based on KPIs and criteria. Recommendations were also made on the review process itself for future assessments as ICOS itself continues to develop.

The second aspect is related to the monitoring of the projects' impact on the development of research infrastructures. While the impact of the RINGO project on ICOS has been important and right in time, it is only one of the several projects that have supported the development of ICOS. The European Commission in cooperation with ESFRI should, therefore, develop an overarching monitoring system that defines long-term KPIs to be applied to all projects related to infrastructure support that benefits an RI.



5

Challenges for implementation of the project results

Although it is very obvious that the RINGO project strongly supported the innovation in ICOS as the Infrastructure Development (INFRADEV) program in general does, the implementation of the results into the operations of the research infrastructure has not always been successful. New technologies and practices developed with project funding need to be supported by constant funding for implementation and day-to-day operation. There is a serious risk that the innovation strands at the interface between funding for development through the Framework Programs of the European Commission, and the funding for implementation and long-term operation from the member states.

In its management plan, ICOS ERIC has taken up this challenge and provided a description of the entire innovation and upgrade process consisting of five phases:

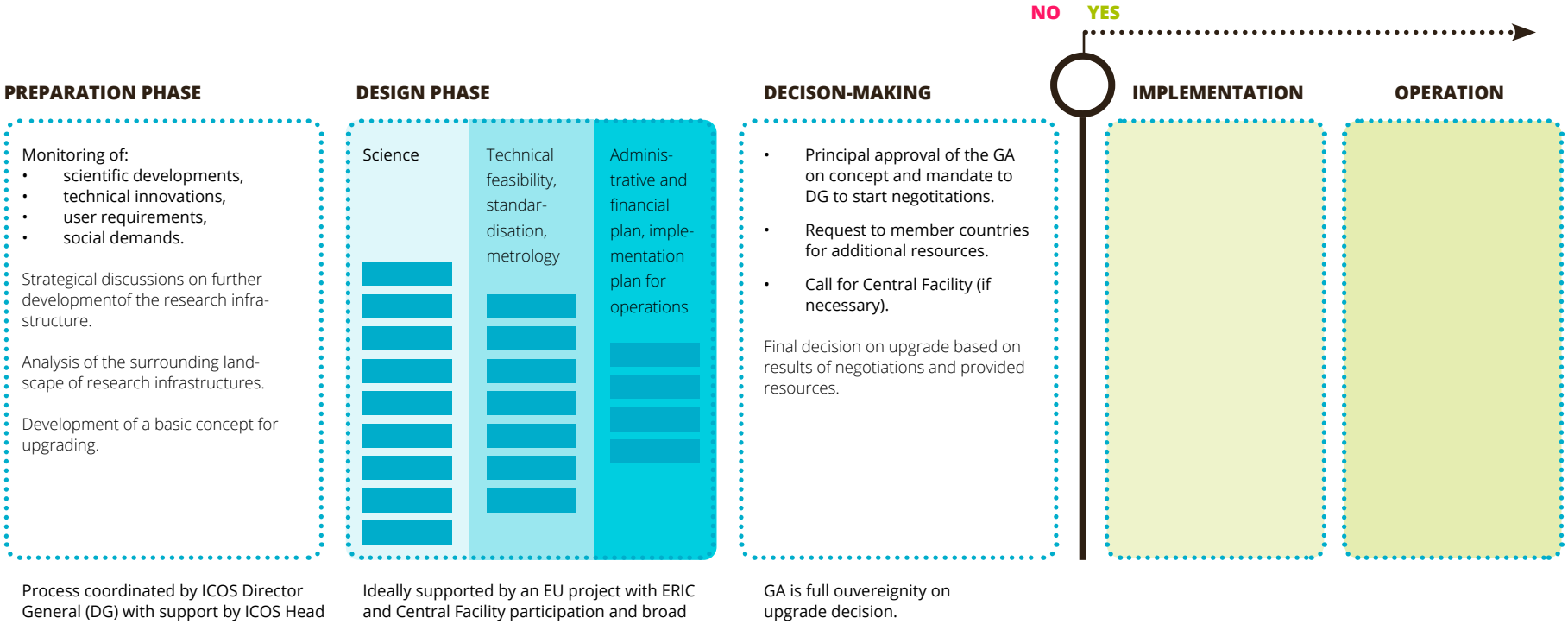
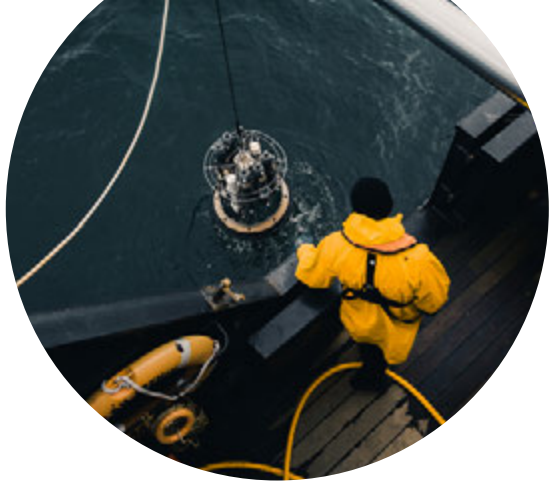
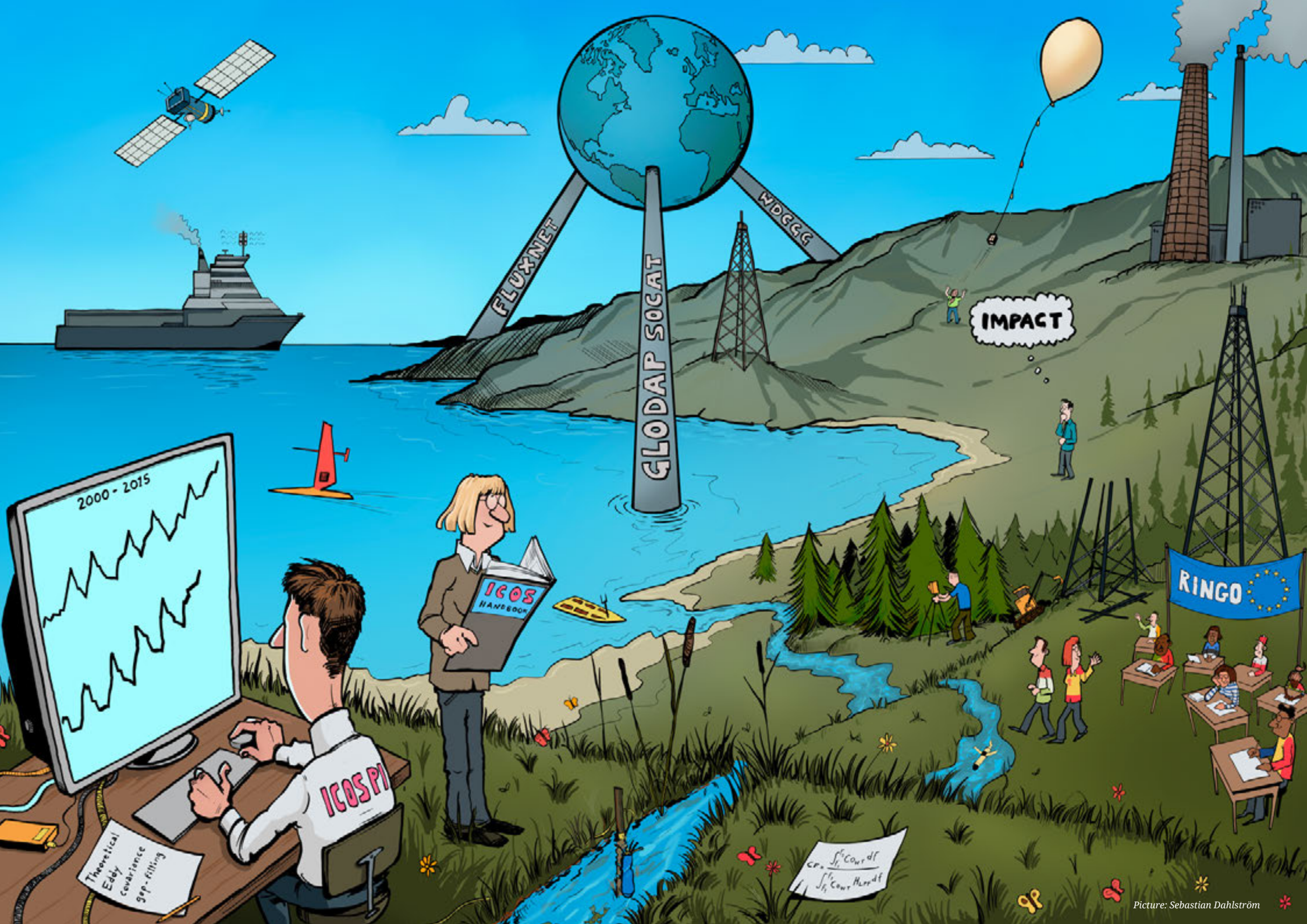


Figure 1: Five phases of the upgrade process of a research infrastructure.

- **THE PREPARATION PHASE** begins when ICOS – as a consequence of continuously monitoring the scientific developments, technical innovation, user requirements and societal demands – draws a strategic conclusion for further development. After analysing the surrounding landscape of research infrastructures, the necessity for a major upgrade of ICOS RI might occur and a basic concept should be developed. During this early phase, the ICOS GA is informed and should be given advice and guidance.
- **THE DESIGN PHASE** is ideally supported by external funding through a project like RINGO. It should involve the broad scientific competence of the ICOS community during the first, mainly scientific, stage. It should deliver studies on the technical feasibility, standardisation and metrology as well as the administrative, financial and operative design. At the end of the Design phase, a comprehensive concept will be presented to the ICOS GA and the Decision phase is initiated.
- **THE DECISION PHASE** should start with a principal approval of the ICOS GA and a mandate to the ICOS ERIC Director General to start further negotiations, particularly with those member countries that are affected, by providing additional resources. In case a new ICOS Central Facility is to be built, the ICOS Head Office will organise a call and the related external evaluation.
- **THE IMPLEMENTATION PHASE** will be initiated, or not, based on the results of the negotiations in **THE DECISION PHASE.** It will lead to **THE OPERATIONAL PHASE.** The Decision phase may last far beyond the end of the project funding. Thus, it might be difficult to monitor the full impact of a project since late impact cannot be communicated. This calls again for a system that evaluates the impact of EU project funding on the development of RIs over longer time scales and a number of projects.





Picture: Sebastian Dahlström