FIVE-YEAR EVALUATION

2020

ICOS

Integrated Carbon Observation System

INTEGRATED CARBON OBSERVATION SYSTEM, ICOS, is a European-wide greenhouse gas research infrastructure. ICOS produces standardised data on greenhouse gas concentrations in the atmosphere, as well as on carbon fluxes between the atmosphere, the ecosystems and oceans. This information is essential for predicting and mitigating climate change. At the time of the evaluation, the standardised ICOS data was based on the measurements from more than 140 stations across 12 European countries. In the beginning of 2021, also Spain joined ICOS. The inter-governmental organisation is financed by its member countries.

ICOS FIVE-YEAR EVOLUTION 2020

AUTHOR Integrated Carbon Observation System Research Infrastructure European Research Infrastructure Consortium (ICOS ERIC)

LAYOUT DESIGN © KRUT Collective, krut.fi

MAP © ICOS Carbon Portal

PICTURES AND GRAPHS © ICOS ERIC: Pictures taken by Konsta Punkka at 12 ICOS stations for #ICOScapes campaign (www.icos-ri.eu/icoscapes).
© Page 33 photographer Melchor González Dávila

PUBLISHED BY ICOS ERIC, Helsinki, June 2021

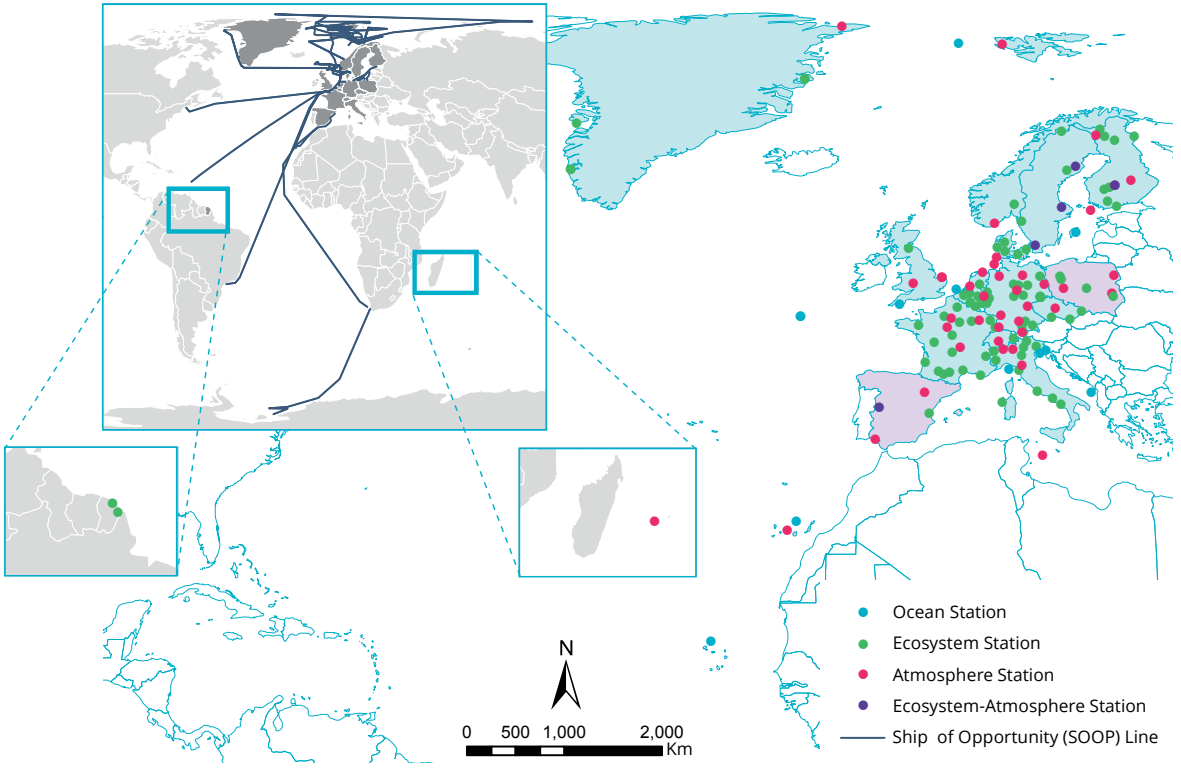
PRINTED IN FINLAND

ISBN 978-952-69501-2-9 (paperback)
ISBN 978-952-69501-3-6 (PDF)

FOR COPIES AND INFORMATION: icos-comms@icos-ri.eu

Table of contents

ICOS Station Network



ICOS Station Network. In the map, light blue indicates current ICOS countries and light violet indicates prospective countries which, in 2020, were soon expected to join ICOS. View the interactive station map at *www.icos-cp.eu/station-map*.

EXECUTIVE SUMMARY

The Integrated Carbon Observation System (ICOS) is a distributed European research infrastructure (RI) that facilitates research to understand the carbon cycle and provide information on greenhouse gases. The source data is gathered by a network of standardised measurement stations in the Atmosphere, Ecosystem and Ocean domains, supported by Central Facilities in each domain, and channelled through them to the Carbon Portal, which represents a one-stop shop for qualified data and data products to a wide range of users. ICOS is coordinated by the ICOS European Research Infrastructure Consortium (ICOS ERIC).

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.

The evaluation was organised around five areas: management; financial management; internal engagement and integration; data and user expectations; and international cooperation. In general terms the Evaluation Committee found that ICOS has completed its implementation phase very successfully, with a well-established governance and management process – including for financial management – making significant progress in providing temporal and spatial data on greenhouse gases in Europe, all channelled robustly and efficiently through the Carbon Portal. A high degree of integration was found across the different elements of ICOS. The outputs of ICOS in the form of data, publications and scientific and outreach events are rising strongly.

ICOS has established itself as a global power in the greenhouse gas (GHG) and climate change arena through strong engagement with all key global organisations that influence international policymaking. ICOS should now prepare to build on these achievements through the development of policies, processes and activities in all the areas evaluated. The Evaluation Committee has identified specific areas for improvement and makes specific recommendations on the possible means to monitor and assess progress in the main categories examined, based on KPIs and criteria. Recommendations are also made on the review process itself, which should be further developed for future assessments as ICOS itself continues to develop.

SUMMARY OF EVALUATION RESULTS

1 Management

1.1. GENERAL MANAGEMENT has been successfully established, but now when the RI is fully operational, thought should be given to the evolution of the organisation and its processes. Surveys gave pointers about delegation of responsibility and decision making, and that high-level meetings would benefit from strategic discussions in greater depth. A review should also be made of delegating more to the people responsible for producing the data.

1.2. OPERATIONAL MANAGEMENT. Robust, high-quality and efficient operations have been set up in a remarkably short time. Data is channelled very effectively through the ICOS Carbon Portal. Further study is needed on whether stations undergoing labelling have sufficient support and resourcing. A plan should be considered to engage with new and existing members to establish sufficient range and density of stations to ensure the temporal and spatial coverage required to fulfil the ICOS mandate.
A strategy and a plan are needed for maintenance and replacement of infrastructure and instrumentation, as well as for the adoption of new technology, to ensure that ICOS these remain at least competitive.

1.3. DATA LIFE CYCLE. The ICOS data life cycle has been set up very robustly and effectively in a remarkably short period of time. A wider range of data services needs to be developed in consultation with the user community.

2 Financial Management

2.1. CORE FUNDING. ICOS financial management with regard to core funding is sound, passing annual audits with no critical remarks, remaining stable in recent years, with a well-structured plan. The equity ratio was also found to be healthy. However – and not surprisingly for an organisation of ICOS's complexity both in terms of structure and members – there are areas needing further work: A closer follow-up of discrepancies between the budget and expenditure; make financial information more accessible; consider setting up a contingency fund to handle unspent funds; provide a benchmark value for equity ratio, with a strategic plan on how to act should the equity ratio deviate from it; establish benchmark values for KPI's.

2.2. PROJECT FUNDING. There is already significant activity in seeking project funding, but there is much potential to build on it and improve on reporting.

3 Internal engagement and integration

3.1. THE INTERNAL ENGAGEMENT of ICOS is solid and there is keen participation in most activities. However, the broad structure calls for internal scientific and technical collaboration, especially with more collective research initiatives across domains. Even if these aspects are considered by Head Office, it would improve the feeling of internal integration if they are reported back to the ICOS community.

3.2. THE INTERNAL INTEGRATION of ICOS should be looked at to better involve the different bodies in an equal way and thus potentially improve their collaboration. A result might be equal contribution by the different RI bodies to ICOS tasks, and common and equal participation in projects. As this is a central part of better communication and collaboration across domains, it has to be assessed in more detail.

4 ICOS data and user expectations

4.1. A PRIORI DESIGN. ICOS has successfully implemented GHG data services that agree with international standards and comply with user and stakeholder expectations. ICOS should continue codesigning standards at international level and take a leading role in future developments, design and standardisation efforts for the global GHG observing system.

4.2. DATA DOWNLOAD. ICOS Carbon Portal enables user-friendly access to data, data products and services. Tracking tools are implemented and data download statistics provided. An increasing user interest for the first two years of data provision has been demonstrated for all domains. The great challenge is that ICOS data is also available from other global repositories, which do not offer tracking possibilities. Therefore, ICOS should actively work with these partners and promote the use of PID and DOI.

4.3. ICOS DATA USAGE. ICOS data, data products and data services are of high value and are widely used across different scientific fields, which is indicated, e.g. by the large and steadily increasing number of scientific publications and citations. Data is widely used in model applications, but not so much in satellite remote sensing. Identifying and connecting to new user groups with the aim of adapting to user needs and widen service provision should be a focus in the future. ICOS should also enhance using its data for educational purposes and find ways to monitor it.

4.4. The ICOS Science Conference and science-facilitating initiatives are successful means for **ACTIVE DATA PROMOTION**. These increase the ICOS visibility and strengthen external collaboration as well as internal engagement, and thus should be forcefully pursued. ICOS is very active in public relations and has been analysing user and stakeholder expectations. This needs to be continued, also by engaging the ICOS community.

4.5. ICOS has prepared ground for **DOWNSTREAM PRIVATE SECTOR COOPERATION**, and offers opportunities for collaboration with manufacturers and service providers. Next, ICOS should facilitate dedicated projects with industry partners and promote using ICOS data for technology and service development by the private sector.

General: The Evaluation Committee fully supports the ICOS Strategy (*https://www.icos-cp.eu/sites/default/files/cmis/ICOS%20Strategy.pdf*) to develop its services based on a steady dialogue with users and stakeholders. Continuous development of the RI is essential for maintaining scientific excellence and enabling frontline research. User needs regarding new data products and services, advanced technologies, and other opportunities should be investigated. ICOS should also continue to work together with other environmental RIs to establish an attractive service portfolio.

5 International cooperation

5.1 ESTIMATION OF THE INTENSITY OF ICOS INTERNATIONAL COOPERATION

5.2 THE INDIVIDUAL LEVEL OF ICOS INVOLVEMENT IN INTERNATIONAL COOPERATION

5.3 ICOS INTERNATIONAL COOPERATION IN THE EYES OF THE STAKEHOLDERS

ICOS has established itself as a global power in the GHG and climate change arena. It is formally involved in all the key organisations, often playing a leading role, and supports observational networks beyond Europe. ICOS is also clearly involved in key global assessment and policymaking forums, enhancing its influence.

ICOS should consider the following: Develop policy regarding MoUs, and establish wider formal recognition of the people representing ICOS on international bodies. Respond to the increasing societal demand to monitor and quantify the anthropogenic component, achieving national-scale carbon accounting, and providing evidence for adaptation. Improve the interface between the scientific perspective and the needs of emission reports, inventories or national adaptation documents. Find alternatives to accommodate researchers in countries that are unable to attain the demanding ICOS criteria, but can greatly contribute to the ICOS agenda and vision.

INTRODUCTION
THE PURPOSE OF THE ICOS EVALUATION AND THE PROCESS

The Integrated Carbon Observation System (ICOS) is a distributed European research infrastructure whose mission is to 'produce optimised, high-precision and long-term observations and facilitate research to understand the carbon cycle and to provide necessary information on greenhouse gases (GHGs).'[1] ICOS also promotes technological developments related to GHGs and aims to 'support, through its high precision data, policy- and decision-making to combat climate change and its impacts'. It achieved legal status as an ERIC (European Research Infrastructure Consortium) in 2015, acquired ESFRI (European Strategy Forum for Research Infrastructures) Landmark status in the 2016 ESFRI Roadmap,[2] delivered its first certified data in 2017 and currently has 11 Member countries and 1 Observer country.

The foundation of ICOS is provided by more than 140 standardised stations that produce data across Europe, coordinated by the ICOS National Networks in the participating countries. The stations have to go through a two-stage quality assurance process before they receive an ICOS label – the first stage to evaluate the site and the second to assess compliance of measurements and data characteristics with ICOS standards. The stations in the National Networks operate in three different domains: Atmosphere, Ecosystem and Ocean, each with its own Monitoring Station Assembly (MSA), with representation by the Principal Investigators (PIs) of the stations.

The Monitoring Station Assemblies monitor and improve the scientific and technical capabilities of the stations in collaboration with Thematic Centres in each domain, as well as Central Analytical Laboratories. The Thematic Centres coordinate the observations of the station and provide support services – for example in the labelling process – and the Central Analytical Laboratories provide calibration gases and gas analyses. The Thematic Centres and Central Analytical Laboratories together comprise the Central Facilities, coordinate and lead operations in their respective fields, and

1 ICOS Strategy: *https://www.icos-cp.eu/sites/default/files/cmis/ICOS%20Strategy.pdf*

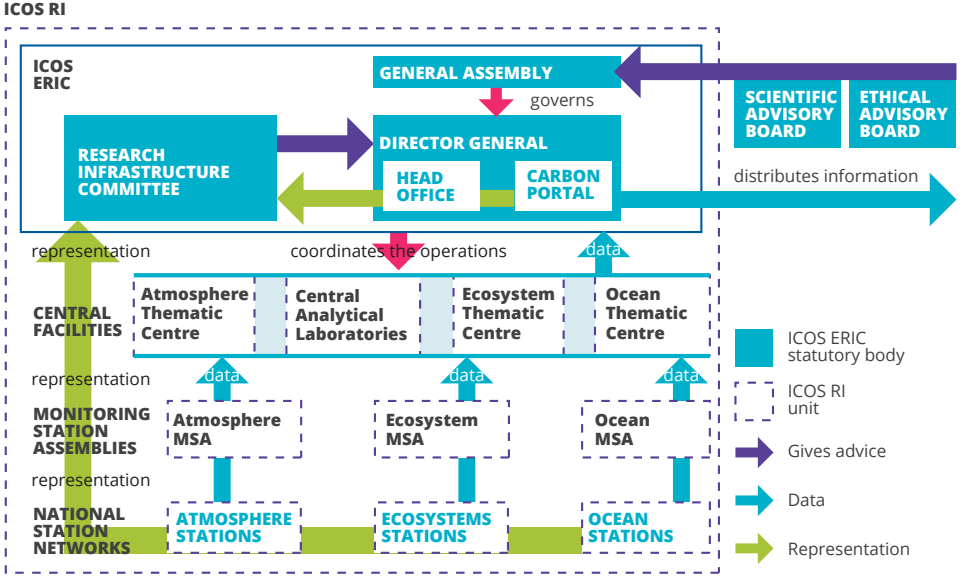
2 *https://www.esfri.eu/roadmap-2016*

process and check the quality of the data gathered from the stations. The ICOS ERIC comprises the ICOS Head Office, providing overall management and coordination of the research infrastructure (RI) operations, and the Carbon Portal, which collects and distributes ICOS data and derived data products.

The overall structure and governance of ICOS is presented schematically in Figure 1, which also displays the General Assembly, which is the governing body, and key advisory boards and coordination committees (Scientific Advisory Board, Ethical Advisory Board and the Research Infrastructure Committee).

The ICOS Statutes state that the ICOS RI to be evaluated in every 5 years. Thus, as the first five-year period was closing in 2019, the General Assembly requested an external evaluation to be done. This was the first time that a distributed research infrastructure of such scale and complexity had been evaluated, so a process had to be devised with no direct precedent. The

Figure 1. Structure and Governance of the ICOS research infrastructure.



General Assembly set up a working party that established Terms of Reference and a set of areas or categories of evaluation. It also stipulated that the evaluation should confirm and evaluate a set of Key Performance Indicators (KPIs) both for the implementation period and ongoing operations. An Evaluation Committee of external experts was appointed in late 2019. The membership of this committee evolved over the following year as some members left due to ill health or competing work commitments, and its final incarnation, broadly spanning all key areas of ICOS activity, as indicated in parentheses, was as follows:

Andrew Harrison, Diamond Light Source, UK (Chair)
Leif Anderson, Department of Marine Sciences, University of Gothenburg, Sweden (Oceans)
Ulla Wandinger, Leibniz Institute for Tropospheric Research, Germany (Atmosphere)
Dan Yakir, Weizmann Institute, Israel (Ecosystems)
Maki Yamada, Swedish Research Council, Sweden (Finance)

The Evaluation Committee also benefited from expert input on compliance with FAIR (Findable, Accessible, Interoperable, Re-usable) Principles from Markus Stocker of the Leibniz Information Centre for Science and Technology in Germany.

The Committee worked with ICOS Head Office over the course of 2020 to elaborate and confirm the evaluation concept, to agree on and collect a variety of documentation and data as evidence for the evaluation, and to develop, implement and analyse the results of surveys of a wide range of ICOS stakeholders and staff. The coronavirus disease 2019 (COVID-19) pandemic made it impossible for the Committee to visit any parts of ICOS during the review period and the evaluation meeting itself was held by videoconference on 20–21 October. The pioneering nature of the review led to extensive engagement between ICOS Head Office and the Evaluation

This report presents the findings of the Evaluation Committee. Additionally, a complementary, separate 'Evidence Report' is compiled by ICOS ERIC, presenting the ICOS data and documentation, together with the outcomes of the surveys and a set of KPI's agreed with the Evaluation Committee.

Committee, and the review process went through several iterations of refining, particularly with regard to the KPIs, as the understanding of which indicators were most appropriate and useful for ICOS's management and stakeholders became clearer. Some of these are expected to evolve further as the strategy and activities of ICOS evolve, a point that will be raised in the concluding section of this report.

This report presents the findings of the Evaluation Committee and should be read as a document that is complementary to the 'Evidence Report' compiled by ICOS ERIC that separately and independently presents the ICOS data and documentation, together with the outcomes of the surveys and a set of KPIs, established and agreed with the Evaluation Committee.

The report is structured around the five categories of activity for which ICOS was assessed, presenting a summary of the key findings, an evaluation of the KPIs and recommendations in each of the following:

1 Management
2 Financial management
3 ICOS internal engagement and integration
4 ICOS data and user expectations
5 International cooperation

Each of these categories was assessed against a set of criteria, each of which had KPIs, all presented in the following sections. Some of the categories are divided into a set of subcategories – for example 'Management' is divided into 'General Management', 'Operational Management' and 'Data Life Cycle'. The report concludes with some overall findings and recommendations, including for future review processes.

The management of ICOS was considered in three areas, together with Financial Management, covered in Category 2. These three subcategories were: 1.1 General Management, the internal management and administration of ICOS; 1.2 Operational Management, the management of stations and Central Facilities; 1.3 Data Life Cycle, the management of the data.

CATEGORY 1
MANAGEMENT

1.1 General management

Any RI must have clear governance, organisation structure and management processes to ensure that it fulfils its mission for its stakeholders, within the framework of a long-term vision and strategy, delivering effective and efficient operations. This challenge is particularly demanding for a distributed RI such as ICOS, which has to function at different levels from measurement stations to the Carbon Portal, across different domains and geographical regions. For this subcategory we considered a set of criteria, all covered by one KPI.

CRITERION 1 Management processes are in place
CRITERION 2 Documentation is available
CRITERION 3 Processes are well executed

SUMMARY OF KEY FINDINGS

- Very comprehensive and well-produced documentation for all areas of governance and management were available, including comprehensive descriptions of processes and responsibilities. Signed cooperation agreements are in place, and there is evidence for well-organised meetings organised by ICOS Head Office, including agendas and minutes. The only item that was incomplete at the time of writing was the Management Plan, due to be finalised at the end of 2020.[3]
- Surveys were made of aspects of General Management at all levels in the organisation. They revealed very high levels of endorsement of the statement that ICOS has a clear mission and strategy and that ICOS has the ability to further develop and improve its activities. Lower levels of support – though still high – were found regarding improvement in the

3 An advanced draft of the Management Plan was available at the time of the evaluation and appeared very satisfactory.

management of ICOS over the past five years and with regard to how well it is managed. Levels of satisfaction decrease as one moves down the hierarchy or further from the centre, from the General Assembly down to station PIs – which is probably true of almost any organisation – with the written responses providing many suggestions for improvements. Surveys scored the effectiveness of meetings highly, but the complementary textual responses suggested a number of areas where improvements could be made.

EVALUATION OF KPI 1 Implementation of basic management processes and availability of the basic documents describing them

Overall, we found KPI 1 to be satisfactorily fulfilled, with everything in place to provide the foundations for effective general management, as well as the foundations for sound financial management (noted below for Category 2), though the surveys did suggest a number of areas of improvement for the effectiveness of processes, outlined below and in the section on Category 2.

CONCLUSIONS AND RECOMMENDATIONS
regarding general management

- ICOS has completed its implementation phase successfully with regard to establishing and documenting an effective management system, and should be congratulated for this achievement. KPI 1 may not need to be used again – at least in its current form – though the surveys did suggest room for improvement or development in some areas. This report is not the place to go into these suggestions in detail, though we do note persistent points made about the effectiveness of some meetings, particularly those of the General Assembly, which could provide a better opportunity to discuss key issues in greater depth, as well the need to delegate greater responsibility within ICOS Head Office. We also note the challenge to ensure that there is good communication between ICOS ERIC and the rest of the organisation – a task that appears to be taken up well judging by the evidence presented under Category 3, but constant vigilance and perhaps adaption of policy and actions will be required, and Head Office will need to continue to work hard to foster communication between all the different elements of ICOS.

- The wealth of information provided by the survey should be used by ICOS Head Office, first to identify key areas for development and then to produce a plan for mitigating actions. A survey should be conducted periodically – perhaps every 2–3 years, in a form that should evolve as the organisation evolves – and the effectiveness of actions should be assessed. The outcome of such reviews should be reported to the General Assembly.

1.2 Operational management

The foundation of ICOS operations is the gathering of data by the measurement stations, distributed geographically and across domains, and coordinated, monitored and supported by the Thematic Centres, with further support provided by the Central Analytical Laboratories. The effective performance of this element of ICOS operations requires the stations to conform to and deliver against agreed and robust operational standards, and to provide reliable temporal coverage, both in the short and long term. The distribution of the measurement stations is challenging as it should provide spatial coverage across Europe that is sufficient to represent the main ecosystems and land cover types, the main climatic regions, represent the geographic and synoptic scale of the European domain, as well as provide a basis for national-scale ICOS-based assessments. They should also keep up with the latest technical developments to ensure that their equipment offers state-of-the-art capabilities, as well as the addition of newly developed capabilities. All of this requires effective management.

CRITERION 1 Availability of technical requirements for ICOS instrumentation
CRITERION 2 Availability of ICOS-approved operational practices for the measurement of variables

SUMMARY OF KEY FINDINGS

- Very extensive documentation is available on station specifications, including their instrumentation, and on operational procedures, held by the Central Facilities and based on extensive discussions in the Monitoring Stations Assemblies.
- The standardisation processes and their documentation have been taken forward within the three different domains: the Atmosphere and Ecosystem domains have developed their own standards and protocols, while for the Ocean domain the instrument requirements and operational

procedures have been developed from existing global guidelines for best measurement practices.[4]

- The surveys indicated a very positive view on the part of the station PIs and Central Facility coordinators of the state of standardisation in ICOS, though many proposals for improvement were provided in the textual commentary, particularly by the station PIs. These included suggestions for greater alignment with the best international standards, and some believe that the requirements of the standardisation process are sometimes too complex and numerous. This may be related to concerns expressed elsewhere in the surveys – see Criterion 3 of this subcategory – that there are insufficient resources to enable compliance in a timely fashion.

EVALUATION OF KPI 2 The availability of technical requirements for ICOS instrumentation

EVALUATION OF KPI 3 The availability of ICOS-approved operational practices

Both these KPIs were found to be highly satisfactory in terms of the extent and quality of the documentation. It was suggested that in future data be gathered to quantify these KPIs numerically, expressed as the percentage of variables that are standardised for instrumentation in each domain – the Atmosphere, Ecosystem and Ocean. Such information is only partially available at present, but where it is, it also indicates a very high level of performance. In the Ecosystem domain there are protocols for operational procedures for all the mandatory variables, while it appears that 87% of the requirements for instrumentation for this domain are available and the rest are not deemed necessary. Such figures are not currently available for the other two domains.

4 Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to Best Practices for Ocean CO_2 Measurements. PICES Special Publication 3, 191 pp

CRITERION 3 Stations are labelled

Once technical standards have been set it is essential that compliance is met, rigorously and in a timely fashion. The process of establishing compliance and then certification is called labelling at ICOS and takes place in three steps: (1) evaluation of the station characteristics, such as the site and technical requirements; (2) assessment, overseen by the Thematic Centres, of how well the station complies to ICOS standards; (3) approval by the General Assembly that the station be accepted into the appropriate ICOS network based on the evaluation report from step 2.

SUMMARY OF KEY FINDINGS

- By the time of the General Assembly meeting of November 2020, 68 of 143 stations had gained Step 3 approval, with 44% of these stations progressing from Step 2 within the year. Reports are available for the labelling process at each station.
- A more detailed breakdown of the extent to which the labelling process has been completed across countries and domains was also provided. This data indicates significant variation of the extent of labelling across countries, and a higher percentage of labelling of Atmosphere stations compared to those for Ecosystem and Ocean, though the labelling process has not been running for very long and the numbers involved are not very large.
- Surveys were conducted of the level of satisfaction regarding the ease, efficiency and extent of completion of the labelling process. These indicated some frustration with the complexity and speed of the labelling process. The 'efficiency' of the process did not get very high scores, with Focal Points in particular expressing ambivalence both in their scores and in their textual commentary. Dissatisfaction is also expressed in the textual commentary, particularly among station PIs, about the level of resources and support or training provided to assist with the labelling process, a reference perhaps to concerns about the complexity of the

labelling process expressed under Criterion 1. Here the scores were more favourable in the Atmosphere and Ocean domains than for Ecosystem.

Table 1. Status of the ICOS station labelling in November 2020.

Type of station	Number of stations*	Number labelled	% of stations labelled
Ecosystem	85	35	41,2 %
Atmosphere	37	26	70,3 %
Ocean	21	7	33,3 %
All	**143**	**68**	**47,6 %**

** Nr of stations for 2020 is counted according to the GA decision in Nov 2019.*

EVALUATION OF KPI 4 Effective station labelling

Some 48% of stations (a total of 68) have been labelled in the two years since the process started, which is a considerable achievement and provides a basis for assessing the capacity in this area. The KPI is not currently formulated to include reference to the speed of labelling. The two-year time framework can, however, be used as a basis for tracking the efficiency and progress in this process. This could be considered in the future, to help identify reasons for bottlenecks and plan to mitigate against them, with the ultimate aim of approaching full station labelling.

The principal reasons affecting the efficiency of the labelling process were related to its complexity and to the resources available. Given that the complexity should be more or less uniform across stations in a domain, it could be inferred that variations in the extent of labelling between countries have some relation to the provision of resources. The number of stations for some countries is small and the statistical significance of labelling levels is low, but in later evaluations these numbers will become statistically more significant.

CRITERION 4 Data coverage in temporal and spatial dimensions is effective

The temporal aspect of coverage concerns the reliability of the stations to provide data, and to do so over a sustained period of time, to enable longer-term trends to be identified. Notably, the temporal perspective is a complex one, as it should provide a continuous observation, covering the daily and seasonal cycles, and provide a basis both for modelling efforts and to obtain the critical annual budgets. But it should also provide extended temporal coverage that accounts for changes in land cover, age effects and disturbances. The spatial aspect relates to the area covered, the density of coverage by stations, and the nature of the different types of area covered. And, as noted above, it should represent the main ecosystems, climates and geography, and national components of the European system. Together, the spatial and temporal coverage needs to be sufficient to allow key conclusions to be drawn about the GHG situation in Europe and more widely over long time periods.

SUMMARY OF KEY FINDINGS

- The reliability of the stations in providing data to the Carbon Portal is greater than 99%.
- The reasons for data losses have been surveyed among station PIs, the most frequently cited being failure in instrumentation and infrastructure.
- The data available for spatial coverage by ICOS is variable across domains. There are clear mappings of the areas covered by the Atmosphere stations, showing good coverage in many member countries but also

47% of stations have been labelled in the two years since the process started, which is a considerable achievement and provides a basis for assessing the capacity in this area.

very significant gaps in those parts of Europe that do not have members. Basic information was provided of the distribution of Ecosystem stations across different types of ecosystem, but not yet for the coverage of the oceans – although an outline was given of the considerations to be made in planning for satisfactory ocean coverage.

- The extent of spatial coverage was covered in the survey on questions to Focal Points, 27% of whom disagreed to a greater or lesser extent with the suggestion that it was adequate in their country, pointing inter alia to the need to improve available resources to rectify this shortfall.

EVALUATION OF KPI 5 Comprehensive temporal data coverage

Temporal data coverage is currently very good, with almost 100% of Level 2 data being delivered through the Carbon Portal. The survey findings on key reasons for failure suggest that temporal coverage is likely to get less reliable unless there is continued investment to ensure equipment and infrastructure to be maintained and ultimately replaced in a timely fashion. This KPI could be developed in the longer term to provide a more comprehensive account of the coverage of raw (Level 0) data and processed and quality-controlled data (Level 2) in all three domains.

EVALUATION OF KPI 6 Comprehensive spatial coverage of observation

The current coverage of Europe by ICOS Atmosphere stations is 81.3% of land area of the member countries (and 75.5% by labelled Atmosphere stations). However, 57% of the land area of Europe (including the European part of the Russian Federation and Greenland) remains without coverage. There is not yet clear mapping of the distribution of stations in relation to different biomes, climate zones and land use, and the KPI might be developed in the future to take these issues into account and include benchmarks based on the range, density and scope of coverage required to provide sufficiently detailed information for key modelling activity, for example as outlined in the report on Task 3.5 of the 'Readiness of ICOS for Necessities of Integrated

Temporal data coverage is currently very good, with almost 100% of Level 2 data being delivered through the Carbon Portal.

Spatial coverage is less satisfactory. A prioritised plan to attract new members for wider spatial coverage in all three domains is required. This may require further analysis of the densities of measurement stations and distribution across types of ecosystem to answer key questions of global GHG behaviour.

Global Observations' (RINGO) project.[5] To quantitatively assess the spatial coverage, this KPI can rely, for example, on comparisons of ICOS station distribution maps vs those of the European vegetation and biomes, and on ICOS's ultimate ability to close the annual European carbon budget (as well as that of other greenhouse gases).

CRITERION 5 New technologies are implemented

SUMMARY OF KEY FINDINGS

- Reports on successive RINGO deliverables together with ICOS annual reports provide information about the technology and methods developed specifically to improve the quality of measurements, including the current status of each, from developmental stages through approval to implementation.
- Surveys were also made of the views of station PIs and Central Facility coordinators on the extent to which ICOS is able to take up technical

5 Ref. Task 3.5 of RINGO project, Moreux et al., 2020. *https://www.icos-cp.eu/observations/projects/ringo/deliverables*

A significant number of respondents, particularly among station PIs, did not rate ICOS's ability to take up new technology very highly, and provided a rich commentary with many suggestions for new or improved technology that should be adopted, as well as strong statements about the need to develop a coherent strategy and delivery plan for new technology.

innovation and what it should do on this front in the future. A significant number of respondents, particularly among station PIs, did not rate ICOS's ability to take up new technology very highly, and provided a rich commentary with many suggestions for new or improved technology that should be adopted, as well as strong statements about the need to develop a coherent strategy and delivery plan for new technology. The great majority of suggestions for new technology concerned satellites and ground-based remote sensing.

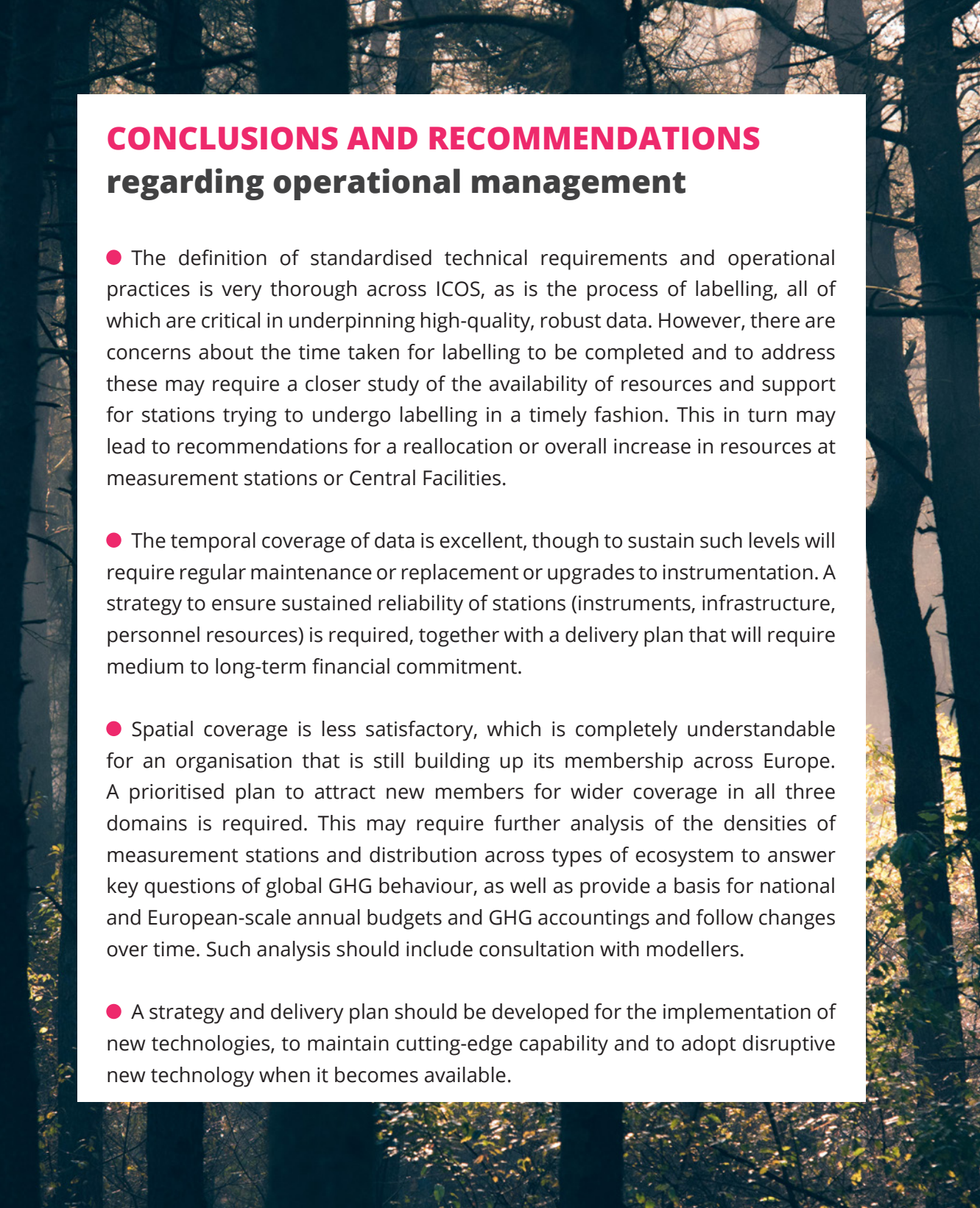
EVALUATION OF KPI 7 Implementation of new technologies

At present this KPI takes the form of a narrative based on a summary of the status of development and technology and methods presented in the Innovation table in the ICOS ERIC report. This indicates that two new

technologies have already passed through General Assembly approval and are being used, with a pipeline of other projects at various stages of development that one could also imagine will become steadily available over the years to come.

This KPI should be developed for future use to have a numerical element, quantifying the development, testing and implementation of new instruments and methodologies. It should also include a description of upstream cooperation with industry. Notably, it should account for two key developments. First, new and improved technologies in addressing ongoing measurements, such as the transition from IR absorption to laser spectroscopy as a key technology in GHG measurements. And second, new technologies that permit the expansion of the current suite of measurements, such as new trace gases, e.g. carbonyl sulphide, stable isotope measurements of GHG and novel remote sensing approaches like solar-induced chlorophyll fluorescence and lidar-based measurements. Some of the new developments may be European and ICOS-based, and the commercialisation of new technologies could be an important part of this KPI.

The rate of roll-out of such technologies will be moderated by the need to rigorously test and qualify its suitability for operational use, as well as by the resources available. This is likely to be more straightforward for the incremental evolution of existing technology than disruptive development, but for both of these cases a coherent, strategic approach should be taken across ICOS. It is noted with approval that the ICOS Strategy, endorsed by their General Assembly in 2019, states a high-level ambition to maintain and in some areas lead the development of the highest technical capability, and that now a more detailed plan should be developed on a rolling basis.



CONCLUSIONS AND RECOMMENDATIONS
regarding operational management

- The definition of standardised technical requirements and operational practices is very thorough across ICOS, as is the process of labelling, all of which are critical in underpinning high-quality, robust data. However, there are concerns about the time taken for labelling to be completed and to address these may require a closer study of the availability of resources and support for stations trying to undergo labelling in a timely fashion. This in turn may lead to recommendations for a reallocation or overall increase in resources at measurement stations or Central Facilities.

- The temporal coverage of data is excellent, though to sustain such levels will require regular maintenance or replacement or upgrades to instrumentation. A strategy to ensure sustained reliability of stations (instruments, infrastructure, personnel resources) is required, together with a delivery plan that will require medium to long-term financial commitment.

- Spatial coverage is less satisfactory, which is completely understandable for an organisation that is still building up its membership across Europe. A prioritised plan to attract new members for wider coverage in all three domains is required. This may require further analysis of the densities of measurement stations and distribution across types of ecosystem to answer key questions of global GHG behaviour, as well as provide a basis for national and European-scale annual budgets and GHG accountings and follow changes over time. Such analysis should include consultation with modellers.

- A strategy and delivery plan should be developed for the implementation of new technologies, to maintain cutting-edge capability and to adopt disruptive new technology when it becomes available.

1.3 Data life cycle

The ICOS data life cycle is the whole chain of actions from long-term observations from across its stations all the way through the Carbon Portal and outwards to a range of users. A reliable, robust, fast and efficient data life cycle is an essential prerequisite to assure the service provision of ICOS, in particular the timely release of comprehensive, quality-assured data for users following the FAIR principles. ICOS defines four levels of data products:

Level 0 or raw data: information or objects obtained directly from human measurement or automated sensors without any further transformation.
Level 1 or intermediate observational data: generated in intermediate steps of Level 1 Near Real Time (NRT) or Level 2 data, for example for internal quality checks and not used as persistent data or outside ICOS. NRT data is a special form of Level 1 data developed for fast distribution with only automated quality control, typically within 24 hrs.
Level 2 data: final quality-controlled data, the main product of ICOS.
Level 3 data: elaborated products, based partly or completely on Level 2 data.

The evaluation of this aspect of management was based on four criteria, each with a KPI.

CRITERION 1 Data workflows are well defined and effective

SUMMARY OF KEY FINDINGS

- A very comprehensive set of documents has been provided, describing the flow of data and metadata from measurement stations through Thematic Centres to the Carbon Portal, together with data processing and quality control along the way.

- Quantitative data on the effectiveness of the data workflows is largely covered under the next criterion; *data is made available in a timely fashion.*
- The response to the survey on definition of workflows and data flow in ICOS was very positive among Focal Points and members of Research Infrastructure Committee (RI COM) and the General Assembly, and less so (but still very positive) for responses from station PIs and Central Facility coordinators. There is also generally a very positive view taken of the improvement of the data by the data life cycle, again less marked from the perspectives of station PIs and Central Facility coordinators. Concerns were expressed on the open responses, particularly from station PIs, about the complexity of some of the processes and the need for greater support from the Central Facilities, as noted too for subcategory 1.2. Some PIs also raised concerns about the communication of data quality problems from the Thematic Centres, particularly in the Atmosphere domain.

EVALUATION OF KPI 8 Definitions of data workflows

This is judged to be highly satisfactory with a complete description of the data and workflows. However, given some of the concerns raised in the surveys, we believe that this KPI should be retained, so that the success of any mitigating actions prompted by the surveys may be assessed.

CRITERION 2 Data is made available in a timely fashion

SUMMARY OF KEY FINDINGS

- Only stations that have received the ICOS label can produce ICOS data, so this naturally limited the earliest date for the provision of such certified data with successive roll-outs of different types of data in the past two years: ICOS Level 2 data was made available in 2018 for Atmosphere, with Level 2 data for Ocean and Ecosystem following in 2019. Such data is made available within the contractually obliged timescale of annual delivery, at the latest within six months of the end of the year in question, and typically one to two months after the release date; NRT data was

first released in 2020 and is typically available within 24 hours of the measurement. The exception is data from Ships of Opportunity (SOOPs) that do not have satellite connectivity, and this can lead to delays of a few weeks once the ship has harboured and found a suitable connection.

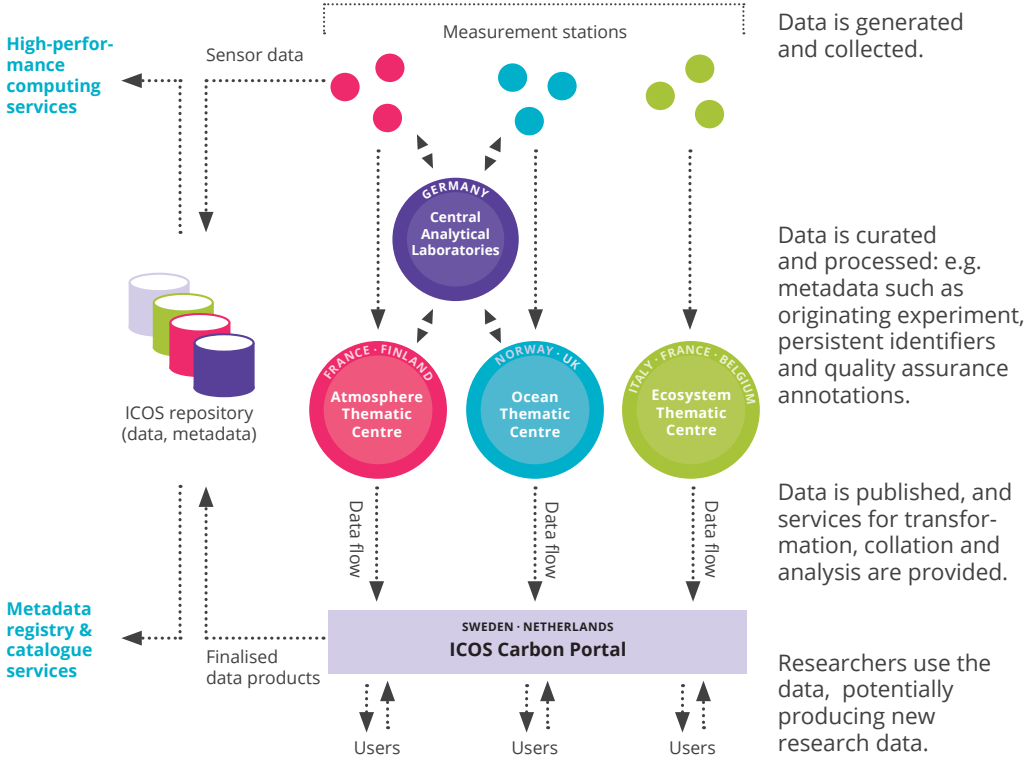
- The surveys put questions relating to timeliness to people at different levels in the ICOS organisation, from station PIs, through Central Facility coordinators to Focal Points and members of RI COM and the General Assembly. The level of satisfaction was lower the closer the respondents were to the measurement stations, with textual responses indicating concerns about processing metadata and manual data, and the speed with which stations can submit data of sufficient quality on time, likely due to insufficient manpower. There was also some dissatisfaction among station PIs about the timely release of Level 2 data.

EVALUATION OF KPI 9 Timeliness of data provision

The primary output of ICOS, the Level 2 data, as well as the NRT data, are generally provided well within the contractually-defined time periods.

In future the KPI could be refined by evaluating the timeliness of individual steps in the data life cycle. The amount of data provided in near-real time could be monitored as well. User expectations (see Category 4) should be considered when delivery times are (re-)defined.

Figure 2. The flow of data from ICOS observation stations to users.



CRITERION 3 Data is compliant with FAIR principles

SUMMARY OF KEY FINDINGS

- An external expert review was conducted by Markus Stocker of the Leibniz Information Centre for Science and Technology in Germany, and this is reproduced in full in the appendix to this document. The report was based on an analysis of RINGO Deliverable D5.5 entitled ICOS improved data life cycle of July 2020 in light of the FAIR principles. This document

presents the latest state of the ICOS data life cycle, and appropriate parts of the text were used as evidence to test how well the data life cycle meets the FAIR Data Principles. Statements could be found for 11 of the 13 sub-principles, and when put to the test, evidence could be found for compliance with nine. Much more detailed analysis and an action plan is presented in the external expert report (Appendix 2).

- The survey asked station PIs and Central Facility coordinators about the value of the Carbon Portal and the ICOS data life cycle to interoperability and reusability and received positive to very positive responses on all counts.

EVALUATION OF KPI 10 Data compliance with FAIR principles

The external expert review found evidence for compliance with nine of the 13 FAIR subprinciples and a plan to achieve full compliance, particularly with regard to interoperability. It is anticipated that this KPI will be retired once compliance is complete.

It should be noted that the ICOS data processing systems were largely developed across the domains a decade ago, and well before the publication of the FAIR Guiding Principles in 2016. The Carbon Portal provides a means of introducing or consolidating FAIR principles for ICOS data. Although the concept of the Carbon Portal was developed in the period 2012–2014, with the Carbon Portal concept paper published in 2014, its design quite naturally met FAIR principles.

All data and data-related services are available via Carbon Portal as the single-access point/ centralised entry gateway. This has been established in a highly efficient manner, with open, easy access and the support of a range of tools.

CRITERION 4 All data and data-related services are available via the Carbon Portal as the single-access point/centralised entry gateway

SUMMARY OF KEY FINDINGS

- There is extensive documentation presenting the data and data services available through the Carbon Portal, most notably in the ICOS Handbook, the RINGO 5.5 Deliverable document, and pages of the ICOS website on data services.[6]
- The Carbon Portal provides free and easy access to a range of data and metadata, and in particular to certified, Level 2 data and NRT Level 1 data, at least as quickly as it is contractually obliged to (Criterion 2).
- The Carbon Portal also provides a range of tools and services, built around the core Simple Protocol and RDF Query Language (SparQL) and data services, and is making an increasing range of elaborated, Level 3 data products available.
- The Carbon Portal has been set up with fast, efficient machine-to-machine workflows with scalable cloud services, facilitating a wider scientific impact of ICOS data.
- The survey found that the majority of station PIs and Central Facility coordinators had searched in the Carbon Portal for data that their unit had provided, with a small percentage of them experiencing difficulties in finding their data.

EVALUATION OF KPI 11 Availability of all data and data-related support and services via Carbon Portal

All data and data-related services are available via Carbon Portal as the single-access point/centralised entry gateway. This has been established in a highly efficient manner, with open, easy access and the support of a range of tools. It is proposed that this KPI be developed in the future to enumerate the data services provided for users, accessed with the aid of a catalogue of services.

6 *https://www.icos-cp.eu/data-services*

CONCLUSIONS AND RECOMMENDATIONS
regarding data life cycle

- The ICOS data life cycle is based on well-defined and effective data workflows, from measurement stations through Central Facilities to the Carbon Portal and beyond. The speed with which data at both Level 1 and Level 2 have been made available across the organisation is highly commendable. However, there do appear to be bottlenecks in the system that should be investigated further and tackled with the aid of a prioritised action plan, redirecting or increasing resources where they are needed most. The surveys already provide some indication of pinch points, particularly at the interface between measurement stations and Central Facilities.

- Progress in achieving full compliance with FAIR principles is very advanced, with an action plan to complete it. The Carbon Portal provides a highly effective means of making data and data services available to the wider user community and should be developed further to offer a wider range of data services, directed by user demand and presented through a catalogue.

CATEGORY 2
FINANCIAL MANAGEMENT

In the Internal Financial Rules, in the framework for ICOS financial management principles, it is stated:
'ICOS RI is a distributed research infrastructure, where the ICOS National Networks, ICOS Central Facilities, Atmosphere Thematic Centre (ATC), Ecosystem Thematic Centre (ETC), Ocean Thematic Centre (OTC) and Central Analytical Laboratories (CAL), are (multi)national nodes of ICOS RI and not part of the ICOS ERIC (European Research Infrastructure Consortium), whereas the Head Office (HO), Carbon Portal (CP) and common activities of the ICOS RI are in the ICOS ERIC.'

This construction of the RI makes it complicated to limit the evaluation of the financial management to just the ICOS ERIC. ICOS ERIC is subject to an audit every year, and therefore the evaluation does not see any reason to mistrust how ICOS's finances have been managed for the period of the evaluation. The evaluation will be based on the survey and the perception of the Evaluation Committee members on the financial management, transparency and information flow regarding the finances and with that, present alternatives for increased understanding of the annual financial reports and financial management.

2.1 Core funding

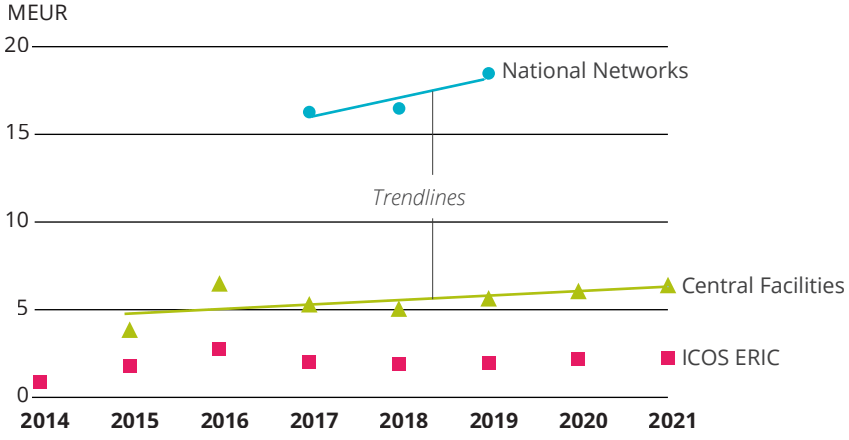
The strategic goal of financial management in a distributed RI such as ICOS is to achieve overall transparency, fiscal discipline, allocation of resources to priority needs, efficient and effective provision of the defined output, and impact as the basis for long-term sustainability of the funding. Furthermore, the analysis of the financial situation, particularly the ability to secure project funding as well as its internal distribution, provides important information about the significance of the RI, its position within the research landscape and the internal integration.

CRITERION 1 The amount of core funding is in line with operations

SUMMARY OF KEY FINDINGS

- ICOS has a very well documented process plan for how their financial management works and has prepared a five-year budget that has been approved by the General Assembly. This five-year plan serves as a reference for the annual budget.
- The annual budgets have been reviewed by the Financial Committee and approved by the General Assembly.
- ICOS ERIC has been audited annually without any critical remarks.
- One of the major difficulties in the financial reporting, also highlighted in the survey, is that the ICOS construction as an RI has so many components with Central Facilities and National Networks, etc. as well as the financial flows of ICOS. These are presented in the annual financial report for ICOS and such complexity leads to the risk that it is perceived as difficult to follow up by the stakeholders.
- Internally, within RI COM, the General Assembly and the Central Facilities, the survey reveals a wide range of levels of satisfaction with the amount of information they receive. While the majority are very satisfied or satisfied, some respondents expressed significant dissatisfaction.
- The survey also revealed a wish to have follow-ups on discrepancies between the budget and the expenditures so that stakeholders can have an understanding of which parts of the budget did not go as planned.
- The annual financial report for ICOS might be difficult for external stakeholders to find on the homepage and since there is no easy way of finding the reports and/or other documents related to the financial management, the perception of transparency could be questioned. However, it should be noted that the annual financial reports for ICOS are evolving each year to make the annual report easier and more comprehensible for stakeholders.

Figure 3. Trends in ICOS core funding since 2014.



EVALUATION OF KPI 12 Amount, trend and volatility of core funding

ICOS core funding has been stable and it seems to have had a well-structured plan. A new five-year budget plan has been drawn up and this gives stakeholders a better chance of assessing the funding needs for the next five years.

In the future a quantifiable KPI would be useful, together with a benchmark value to prompt action if the KPI falls below the benchmark value.

CRITERION 1 Measures to monitor mid-term financial sustainability are implemented

SUMMARY OF KEY FINDINGS

- The survey revealed that in general, the members of the General Assembly are of the opinion that the financial resources have been sufficient while RI COM members and station PIs are a lot more divided and on average much less satisfied with the distribution of resources across different parts of ICOS.

- Within ICOS the funding has been secure for both ICOS Head Office and the Carbon Portal. The survey indicates that the station PIs and Central Facility coordinators do not feel that the resources they are provided with are sufficient.
- Data to calculate the equity ratio were gathered from the ICOS ERIC annual financial reports (see values below).

EVALUATION OF KPI 13 Equity ratio (equity / total assets = equity ratio)

The equity ratio gives an understanding of the situation regarding ICOS Head Office unspent funds. An equity ratio of 100% means that all the assets in ICOS are financed of equity and ICOS has no loans or debts, while an equity ratio around 50% means that the assets in ICOS consists of both equity and loans or debts. A higher equity ratio means better long-term stability. The unspent funds from a previous year accumulate to equity and therefore the equity

The members of the General Assembly are of the opinion that the financial resources have been sufficient while RI COM members and station PIs are a lot more divided and on average much less satisfied with the distribution of resources across different parts of ICOS.

Table 2. ICOS ERIC Equity ratios 2015–2019.

Year	Equity ratio	Percentage
2015+2016	910 574 ÷ 4 783 640	= 19%
2017	1 079 755 ÷ 2 089 632	= 52%
2018	1 079 755 ÷ 2 089 632	= 48%
2019	977 992 ÷ 2 157 410	= 45%

ratio can help the stakeholders to assess what the unspent funds are relative to the total assets. The following should be noted:

- The equity of ICOS Head Office consists of retained earnings from previous years, i.e. unspent funds.
- Although the Carbon Portal is part of ICOS ERIC, it has its own bank account and therefore the host institution in Lund manages any unspent funds the Carbon Portal may have. The data to determine this KPI from the annual financial reports for ICOS ERIC is as presented in Table 2. We therefore judge that the ICOS ERIC equity ratio is good.

CRITERION 3 Risk mitigation methods are in use

SUMMARY OF KEY FINDINGS

- The survey presents a divided view of whether any unspent funds or a contingency fund should be centralised or remain within the different parts where the unspent funds have occurred.
- The survey showed that some of the National Network stations experienced challenges with future funding, but the majority of the National Networks have secured funding over the next couple of years, while the certainty of funding decreases after 2022 because of the decision cycles of the organisations funding the national network stations.

EVALUATION OF KPI 14 Mid-term financial sustainability

For the evaluation period, the financial situation has been sustainable and well-functioning.

For the future, a clearly-defined and quantifiable KPI should be defined for mid-term financial sustainability, enabling the value to be tracked over time and to help inform any corrective action needed.

CONCLUSIONS AND RECOMMENDATIONS
regarding core funding

ICOS financial management is sound and has passed annual audits with no critical remarks. Core funding has been stable, and it seems to have a well-structured plan. The equity ratio was also found to be healthy. However – and not surprisingly for an organisation of ICOS's complexity and with so many members, each with their own way of funding the various components of the ICOS network – there are challenges that will require ongoing work, much of which is already in hand:

- A closer follow-up on discrepancies between the budget and expenditure is desirable. The Evaluation Committee was told that is in the pipeline and should be implementing in the near future.

- Develop the ICOS webpage to make the financial information more available and accessible. Provide a financial section under its own tab for easy access.

- In order for the equity ratio to be useful for ICOS, a benchmark value should be provided, and a strategic plan should be drawn up if the equity ratio deviates from this plan.

- It is hard to apply the equity ratio to other parts of ICOS – for example the Central Facilities – since they are not part of the ICOS ERIC legal entity. Instead, the Central Facilities' finances come under those of their host institutions, so to be able to calculate their equity ratios would require the balance sheet total from their own financial statements.

- Unspent funds are obviously meant to be spent since they arise either from over-budgeting or a delay in cost – which is still a deviation from the budget. The ICOS Financial Committee should investigate the possibility of starting a contingency fund and propose the possible size of that contingency fund.

- There might be issues regarding the funding of Central Facilities or National Networks, for example, and how those funds are allowed to be transferred to a different recipient than the one primarily intended. That is, if a Central Facility or a National Network station has unspent funds, the funds might be a part of a government contribution, so there may be financial rules that tie the funds to the facilities or the stations.

- Find a sustainable model for handling unspent funds or a contingency fund. It seems that there is an agreement that a central fund for unspent funds or contingency fund is needed, but it is not clear how this could be created in a manner that is compatible with the current ICOS organisation.

2.2 Project funding

The ability to secure project funding as well as its internal distribution provides important information about the significance of the RI, its position within the research landscape and the internal integration.

CRITERION 1 Project funding is actively sought and reported

CRITERION 2 Project funding is effectively used and its usage is monitored

SUMMARY OF KEY FINDINGS

- The majority of station PIs who responded to the survey think that European Union (EU) projects are important financial resources but also stress that they do not feel they are part of the financial planning regarding the said EU projects.
- The project funding to finance ICOS ERIC core activity has increased over the years. It appears to be unknown for 2015–2016, €236 000 for 2017, €643 000 for 2018 and €280 000 for 2019.
- The impact on project funding for the rest of ICOS cannot be found in the material provided for the evaluation.
- ICOS ERIC has coordinated and participated in the writing of several successful project proposals, which has increased the funding available for ICOS's development. With systematic application writing and higher success rate with proposals a more secure funding stream can be achieved.

EVALUATION OF KPI 15 Amount, trend and volatility of external funding

A summary of the external funding for the whole of ICOS is lacking in the annual financial reports, so evaluating this KPI was not possible now.

CONCLUSIONS AND RECOMMENDATIONS
regarding project funding

- There is already significant activity in seeking project funding, but there is still potential to build on this and improve on reporting.

- Reporting should be made concerning the ICOS proposals for external funding, including success rates and the amounts secured.

- In the same way as for the other finance-related KPIs a quantifiable KPI with a benchmark value would be useful. The KPI for this could be posted under the finance section under the ICOS homepage.

CATEGORY 3
INTERNAL ENGAGEMENT AND INTEGRATION

ICOS consists of different types of organisations and institutes, with different agendas and histories and different cultural, political and linguistic backgrounds. Thus, the perceived purpose of ICOS, the motivation to be part of it and the expectations from it vary among its members. This is directly linked to the capacity of the RI community and its ability to develop and maintain strong integration within the RI and ensure long-term operability of the infrastructure.

3.1 Internal engagement

'Engagement' refers to a range of behaviours: willingness to and interest in participating in activities – the signs of motivation.

CRITERION 1 ICOS participants feel that their work is recognised, identify themselves as ICOS partners and are active in branding ICOS

SUMMARY OF KEY FINDINGS

- ICOS participants have a strong feeling of identifying themselves with ICOS.
- Principal Investigators feel that their work is recognised as important by ICOS.
- ICOS participants engage actively in the use of ICOS branding in their everyday work.
- The promotion of ICOS via social media could be further strengthened among the RI community members.

EVALUATION OF KPI 16 Members identify with ICOS

It is clear that ICOS participants at all levels feel well integrated in, and strongly identify themselves with, the RI. The people collecting the data feel

that their work is well recognised and important. ICOS is well branded by the community members in their presentations and other work, however, ICOS could be more visible through the RI community members' social media accounts.

This KPI shows the strong engagement of ICOS participants and it is important to follow this in future evaluations in order to prevent any potential slack in the organisation.

CRITERION 2 ICOS participants are interested in and participate in common activities, as well as take part in organising them

SUMMARY OF KEY FINDINGS

- RI members participate in RI events relatively actively, but participation in other domains' meetings is not widely practised.
- There is an active participation in the ICOS Science Conference among all respondent groups, as is participation and organisation of other ICOS events.

EVALUATION OF KPI 17 People are motivated

ICOS participants are very committed and engaged in RI activities. The basic organisation of Atmosphere, Ecosystem and Ocean stations makes it logical to engage in the own domain. However, as there are many common aspects and the overarching goal of ICOS needs the complete view, much can be gained with more cross-domain activities. This aspect should be one of the key points in future ICOS activities. This KPI is a key to follow the motivation for and involvement in future ICOS operations.

> ***ICOS participants are very committed and engaged in RI activities.***

CONCLUSIONS AND RECOMMENDATIONS
regarding internal engagement

- The internal engagement of ICOS is solid, with people being highly motivated and having a strong sense of identifying themselves with the RI. There is a dynamic branding of ICOS in people's everyday work, but the ICOS community could be more active on social media. There is a keen participation in RI activities, but less so across domains. To strengthen the latter, PIs request more collective research initiatives across domains.

3.2 Internal integration and structure

Word 'integration' refers to the RI's ability to include different parts of the RI into activities, the ability to improve activities and respond in an agile way to new opportunities or challenges, and the potential for improving the RI's structure.

CRITERION 1 Internally, ICOS is a well-integrated organisation, in which participants feel properly included

SUMMARY OF KEY FINDINGS

- About half of the ICOS participants agree that ICOS is well integrated internally.
- The communities within the National Networks are well integrated into ICOS activities, and the General Assembly is well connected to their national ICOS communities.
- There is potential to improve the collaboration between the various Monitoring Station Assemblies, as well as between the different Central Facilities.
- There is a feeling that the different Central Facilities do not contribute equally to ICOS tasks, nor do they participate in projects in a common and equal way.
- The Heads of Units agree that the different domains contribute to internal tasks.

EVALUATION OF KPI 18 The organisational structure of ICOS is inclusive

It is clear that ICOS in general is well integrated and is inclusive. However, in a diverse organisation like this there are always parts that can be improved. It must be the role of the Head Office to facilitate stronger communication and collaboration across the different Monitoring Station Assemblies and

Central Facilities, and supporting them to contribute equally to ICOS tasks.

This KPI is at the centre of the RI and it is thus important to assess how it develops in future evaluations.

CRITERION 2 The ICOS organisation has the ability to improve its activities and respond in an agile way to new opportunities or challenges

SUMMARY OF KEY FINDINGS

- The Focal Points generally feel that ICOS is capable of improving its activities, while the RI COM is less convinced.
- The RI COM is concerned that Head Office does not support the Monitoring Station Assemblies sufficiently and doesn't collect feedback from them in order to improve ICOS internal organisation.
- The Focal Points, on the other hand, agree that Head Office supports them and their National Network adequately.
- The Heads of Units agree that events organised within ICOS have improved over the last five years, as has the management of projects.
- The integration of the Carbon Portal into ICOS activities can be improved.

EVALUATION OF KPI 19 The organisational structure of ICOS enables the improvement of activities

Even if the majority of ICOS activities work well, there is a constant need for Head Office to push for improvements. The integration of the Carbon Portal into the ICOS is limited in part by a lack of support from the domains and in part by technical limitations of the Thematic Centres. The Carbon Portal also felt that their operation is sometimes hampered by complicated management processes. These aspects have to be looked at to see how they can best be improved.

This KPI is yet another important measure of how well the RI works and should be included in future evaluations.


NILU
PICARRO

CRITERION 3 ICOS has potential for an alternative and improved structure

SUMMARY OF KEY FINDINGS

- About half of the survey participants had a strong feeling about the need of changing the current structure of the ICOS.
- The suggestions put forward mostly related to organisational changes like adding support structures, making the organisational structure more equal, and simplifying the structure.
- There were also suggestions related to changing the decision-making by re-distributing decision-making power and adding clarity to the organisation.
- The Central Facilities group felt a strong need of including the Central Facilities into the ERIC.

EVALUATION OF KPI 20 The organisational structure of ICOS functions well in managing the RI

In an organisation covering multiple levels and domains, it is normal for participants to sometimes feel lost. Thus, it is relevant to simplify the structure as much as possible and also have a clear and open information flow. These aspects should be initiated by the General Assembly.

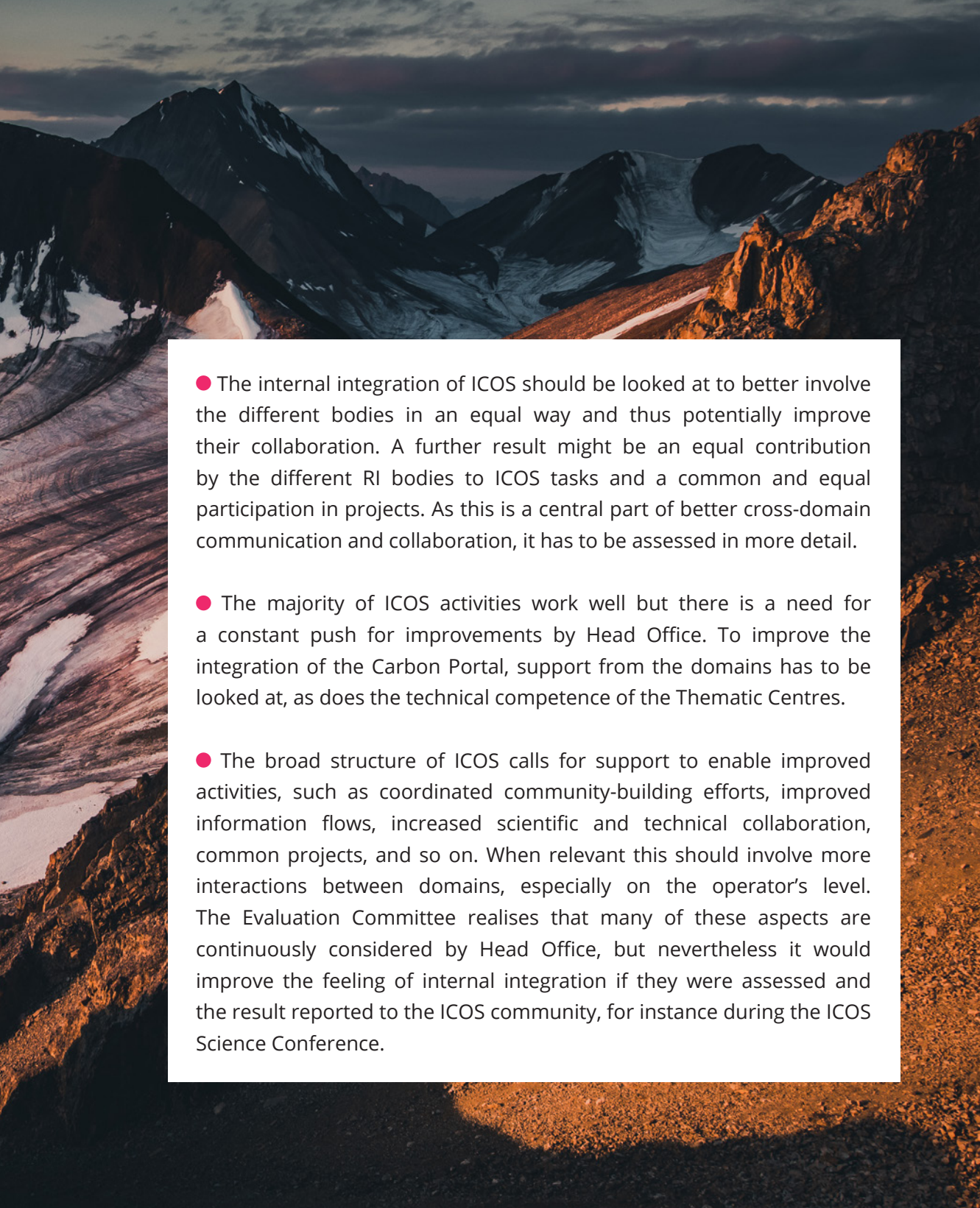
This KPI is straightforward and should be followed in future evaluations.

In an organisation covering multiple levels and domains, it is normal for participants to sometimes feel lost. Thus, it is relevant to simplify the structure as much as possible and also have a clear and open information flow.

CONCLUSIONS AND RECOMMENDATIONS
regarding internal integration and structure

The current structure of the ICOS works, but the Evaluation Committee suggests assessing whether it can be simplified to make it easier to navigate the organisation.

- The decision-making process could be looked at to see if it can be improved by delegating more to the people responsible for producing the data. Such a structure might be improved by including the Central Facilities in the ERIC. Other organisational changes that should be considered are adding support structures (e.g. *'creating a Central Facility for calibration of instruments and manage spare sensors' and 'creating a task force that helps labelling the data'*).



- The internal integration of ICOS should be looked at to better involve the different bodies in an equal way and thus potentially improve their collaboration. A further result might be an equal contribution by the different RI bodies to ICOS tasks and a common and equal participation in projects. As this is a central part of better cross-domain communication and collaboration, it has to be assessed in more detail.

- The majority of ICOS activities work well but there is a need for a constant push for improvements by Head Office. To improve the integration of the Carbon Portal, support from the domains has to be looked at, as does the technical competence of the Thematic Centres.

- The broad structure of ICOS calls for support to enable improved activities, such as coordinated community-building efforts, improved information flows, increased scientific and technical collaboration, common projects, and so on. When relevant this should involve more interactions between domains, especially on the operator's level. The Evaluation Committee realises that many of these aspects are continuously considered by Head Office, but nevertheless it would improve the feeling of internal integration if they were assessed and the result reported to the ICOS community, for instance during the ICOS Science Conference.

CATEGORY 4
ICOS DATA AND USER EXPECTATIONS

According to its statutes, ICOS '*shall provide effective access to coherent and precise data to facilitate research into multi-scale analysis of GHG emissions, sinks and their driving processes by making available measurement protocols, long-term data and data products. Technological developments and demonstrations related to GHGs shall be promoted by the linking of research, education and innovation*' [Statutes of ICOS ERIC, 2015].

This category aims at investigating whether ICOS has been implemented in agreement with the pre-defined tasks and in compliance with the user needs, and thus is able to provide optimised services which best suit the user and stakeholder expectations. Five subcategories are assessed in this context by applying appropriate KPIs: a priori design, data download, data usage, active data promotion and private sector cooperation.

4.1 A priori design

ICOS is considered being the European contribution to the global GHG observation system. Therefore, it is essential that the research infrastructure is designed and developed in agreement with international standards and actively contributes to the global coordinating initiatives.

CRITERION 1 ICOS participates or enables participation in international efforts to codesign standards for ICOS measurements

SUMMARY OF KEY FINDINGS

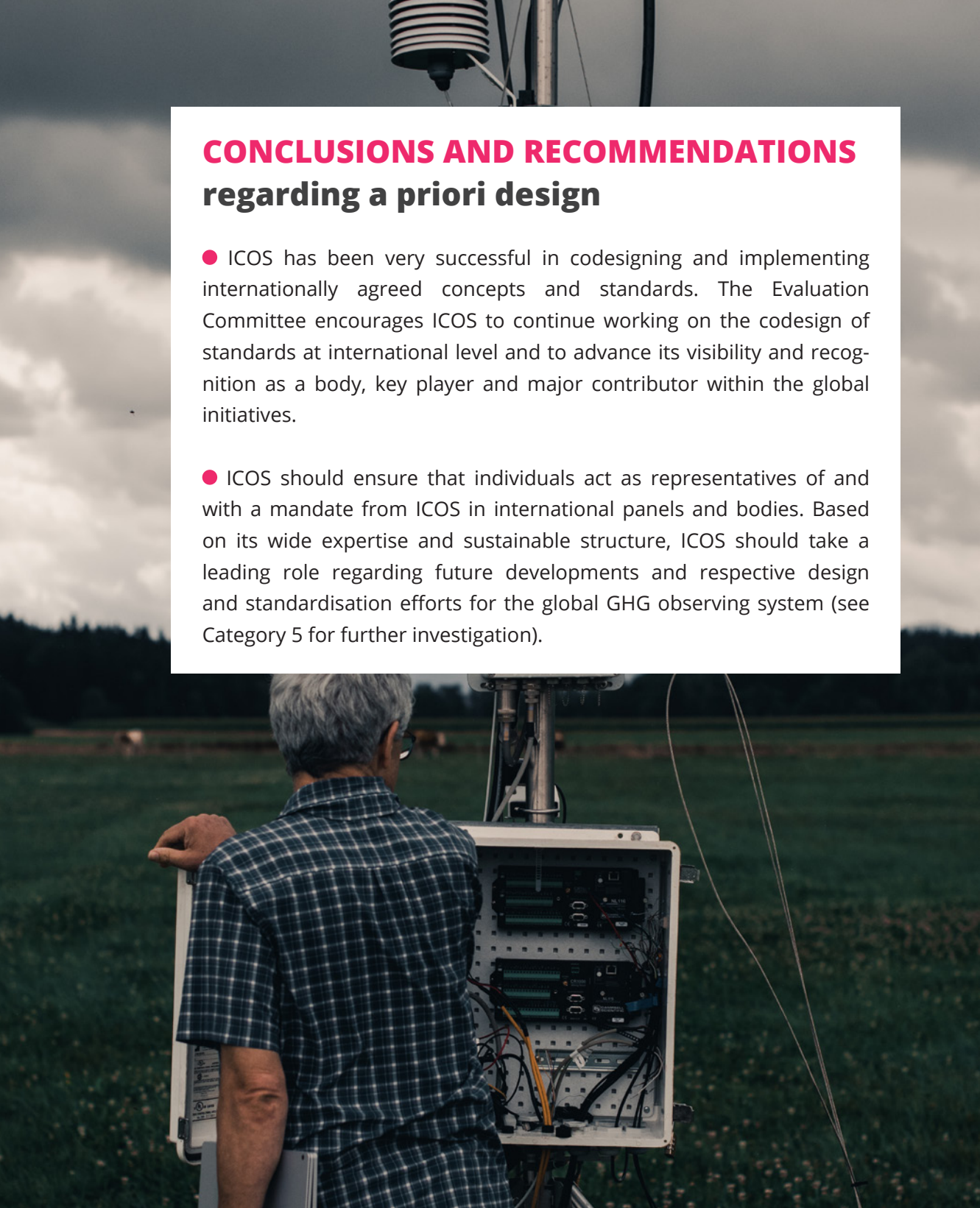
- ICOS has been involved in the introduction and the continuous update of the Global Climate Observing System (GCOS) Essential Climate Variables (ECVs) and the Global Ocean Observing System (GOOS) Essential Ocean Variables (EOVs).
- During the design phase, key persons within ICOS were participating in different GCOS panels and working groups.

- The ICOS design process has been well supported by dedicated EU projects such as the ICOS Preparatory Phase Project (PPP), the Integrated non-CO_2 Greenhouse Gas Observing System (InGOS) and the ICOS improved sensors, network and interoperability for the Global Monitoring for Environment and Security, GMES (ICOS-INWIRE). In addition, the participation of ICOS partners in numerous EU projects enabled bridging to international activities such as the Global Atmosphere Watch (GAW), GCOS and the Group on Earth Observations (GEO).
- ICOS observations were shaped in international cooperation with respective networks, research infrastructures and agencies (the World Data Centre for Greenhouse Gases WDCGG, the Surface Ocean CO_2 Atlas SOCAT, FLUXNET), including standardisation.
- ICOS key people have been involved in international panels of GCOS, the World Meteorological Organization (WMO) and FLUXNET.

EVALUATION OF KPI 21 ICOS-related participation in international efforts to codesign standards for ICOS measurements

ICOS has been designed and implemented following internationally agreed concepts and is well integrated in international initiatives and global measurement networks. Key persons at ICOS have been actively involved in the international efforts to establish a standardised global GHG observing system. It is concluded that ICOS performs very well regarding participation in international efforts to codesign standards for global GHG observations.

KPI 21 mainly serves to evaluate the success of the ICOS design and implementation phases. Nevertheless, it should be followed up in the future to monitor how ICOS is involved in developing new observation capabilities and setting new standards at the international level. Quantitative measures such as the number of ECVs/EOVs covered by ICOS and the number of international cooperation activities to standardise observations might be considered.



CONCLUSIONS AND RECOMMENDATIONS
regarding a priori design

- ICOS has been very successful in codesigning and implementing internationally agreed concepts and standards. The Evaluation Committee encourages ICOS to continue working on the codesign of standards at international level and to advance its visibility and recognition as a body, key player and major contributor within the global initiatives.

- ICOS should ensure that individuals act as representatives of and with a mandate from ICOS in international panels and bodies. Based on its wide expertise and sustainable structure, ICOS should take a leading role regarding future developments and respective design and standardisation efforts for the global GHG observing system (see Category 5 for further investigation).

4.2 Data download

ICOS has set up the Carbon Portal as a central service centre for providing access to data, data products and data services. Appropriate data download statistics serve to measure the success of these efforts.

CRITERION 1 ICOS data is downloaded from the Carbon Portal by users in all ICOS domains
CRITERION 2 ICOS data is downloaded via other portals

SUMMARY OF KEY FINDINGS

- The Carbon Portal is the entry point for all ICOS data services. It has established means to construct download statistics (e.g. by domain, data type, station, year, country of user, etc.) and track the use of data via Persistent Identifier (PID) and Digital Object Identifier (DOI). The first labelled ICOS data was available from the Carbon Portal in 2018. Since the station labelling process is not completed yet, the availability of labelled ICOS data and respective download statistics is still limited.
- In recent months (until October 2020), several hundred to several thousand datasets per domain (Atmosphere, Ecosystem, Ocean) and month have been downloaded. 1000–1500 downloads per months are counted on average for the Atmosphere Level 2 carbon dioxide (CO_2) data product in the period November 2018 – October 2020.
- Data from ICOS stations (pre-ICOS, non-labelled) can also be downloaded individually or as part of global datasets from other repositories (WDCGG, the National Oceanic and Atmospheric Administration NOAA/ICOS Observation Package (ObsPack) GLOBALVIEW, FLUXNET, SOCAT). Respective download statistics have not been available up to now. However, ICOS is working on tracking datasets via these routes in the future by promoting the use of PID and DOI.
- According to the user survey, so far less than one third of the users of ICOS-related data downloaded their data from the Carbon Portal. However,

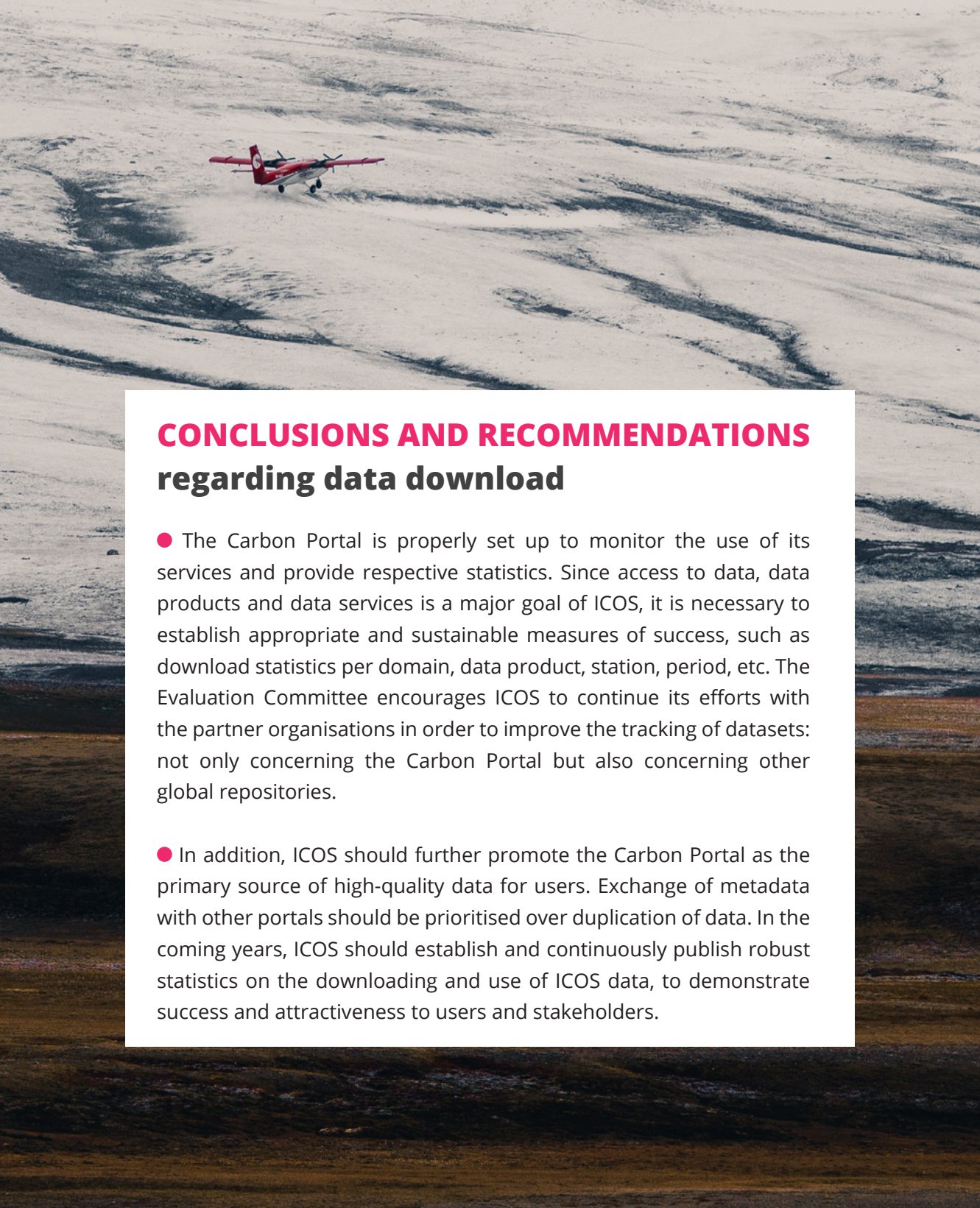
most of the users declared that they know what ICOS is (score 4.6 out of 5). They found the data of high quality (score 4.3 out of 5) but were less satisfied with the timeliness of the data (3.9 out of 5).

Figure 4. ICOS data downloads 2017–2020.
ICOS data use statistics in Carbon Portal: *data.icos-cp.eu/stats*

EVALUATION OF KPI 22 Total amount of data downloads

ICOS has successfully implemented means and measures to establish sustainable data download statistics for the Carbon Portal. Tentative numbers are available for the period 2018–2020 and indicate increasing user interest in data from all domains. For the Atmosphere Level 2 CO_2 data product, a continuously high download number of the order of 1000–1500 downloads per month over two years has been demonstrated already. However, since ICOS data is available from other repositories as well, e.g. as part of global datasets, a complete tracking of ICOS data is not possible up to now.

At the end of the implementation phase, download statistics are limited and provide tentative insight only. However, KPI 22 is considered as an important performance indicator for ICOS in the long term.



CONCLUSIONS AND RECOMMENDATIONS
regarding data download

- The Carbon Portal is properly set up to monitor the use of its services and provide respective statistics. Since access to data, data products and data services is a major goal of ICOS, it is necessary to establish appropriate and sustainable measures of success, such as download statistics per domain, data product, station, period, etc. The Evaluation Committee encourages ICOS to continue its efforts with the partner organisations in order to improve the tracking of datasets: not only concerning the Carbon Portal but also concerning other global repositories.

- In addition, ICOS should further promote the Carbon Portal as the primary source of high-quality data for users. Exchange of metadata with other portals should be prioritised over duplication of data. In the coming years, ICOS should establish and continuously publish robust statistics on the downloading and use of ICOS data, to demonstrate success and attractiveness to users and stakeholders.

4.3 ICOS data usage

Monitoring the use of data is key to understanding user needs and expectations, evaluating the scientific value of ICOS data, and quantifying the success of the research infrastructure in terms of performance and impact. ICOS data is used in science and education in different fields and by different communities. Therefore, several criteria and KPIs are applied in the evaluation of ICOS data usage.

CRITERION 1 ICOS data is used and cited in scientific publications

SUMMARY OF KEY FINDINGS

- ICOS has established an online database with references to ICOS-related scientific publications (*www.icos-cp.eu/science-and-impact/society-impact/references*). By August 2020, ICOS had collected 870 entries from its contributors of papers published since 2010, the year when ICOS funding started at national level.
- In August 2020, ICOS ERIC performed an extensive literature search to identify additional ICOS-related papers, which resulted in another 534 publications that have been added to the database.
- The total number of ICOS-related publications published by the end of 2019 was 1273. The annual number increased from about 100 in 2013 to 240 in 2019.
- The number of citations of the reported ICOS-related publications by the end of 2019 was 27 251. The annual number increased from 1160 in 2013 to 6888 in 2019.

Between 2010 and 2019, altogether 1273 scientific ICOS-related publications and 27 251 citations of these ICOS-related publications have been counted. The yearly numbers are steadily increasing.

Figure 5. ICOS related publications 2009-2019.

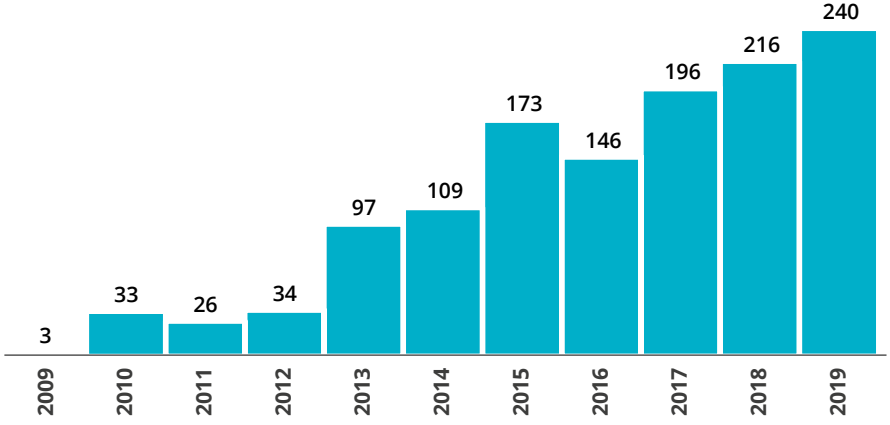
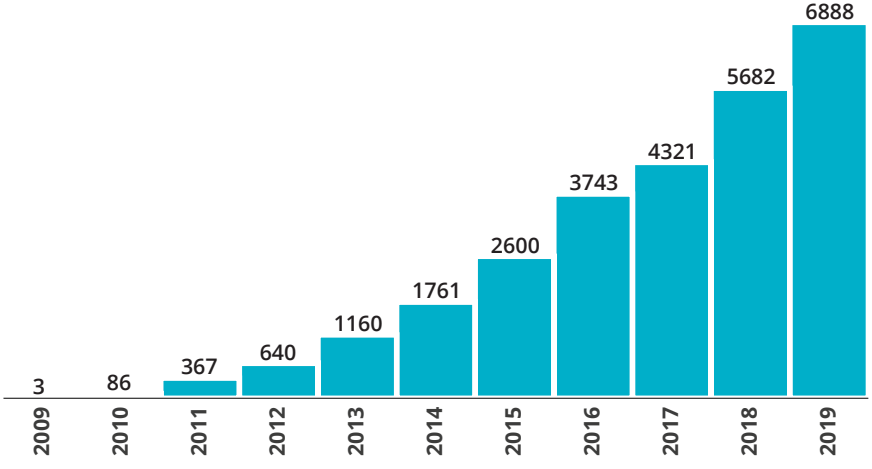


Figure 6. Number of ICOS related citations in publications.



Link to full list of references on ICOS website:
https://www.icos-cp.eu/science-and-impact/society-impact/references

EVALUATION OF KPI 24 Usage of ICOS data in publications and number of citations of publications using ICOS data

ICOS has demonstrated high publication and citation numbers during the design and implementation phases. Between 2010 and 2019, altogether 1273 scientific ICOS-related publications and 27 251 citations of these ICOS-related publications have been counted. The yearly numbers are steadily increasing. ICOS performance with respect to KPI 24 is very good.

KPI 24 is important for monitoring the use of ICOS data in the long term. It shall be applied together with the KPIs for Criterion 2 (see below), which provide insight into specific fields covered by the publications.

CRITERION 2 ICOS data is used across different scientific fields

SUMMARY OF KEY FINDINGS

- According to the sorting by Clarivate group of Web of Science, ICOS-related publications are associated with 58 categories. Most of the publications are related to meteorology and atmospheric sciences (424 papers, 37% of all papers), followed by environmental sciences (380 papers, 34%).
- ICOS data is used in regional and global models. ICOS started analysing the various applications and has provided several examples, such as:

  ICOS atmosphere data has been assimilated in different regional inversion models, e.g. in the context of the European atmospheric transport inversion comparison (EUROCOM) project (six different models).

  ICOS ecosystem data has been used to develop, calibrate and validate the parameterisations in global dynamic vegetation models, e.g. in the framework of the TRENDY experiment (Trends in net land-atmosphere carbon exchange over the period 1980–2010; nine different models). These models also provide input for the Global Carbon Project yearly analysis of the global carbon cycle and for inversion models.

ICOS ocean data provided via SOCAT serve as input for the Global Carbon Project and are used in various global ocean biogeochemical models.

ICOS CO_2 NRT observations has been used to optimise the Copernicus data on CO_2 fossil fuel fluxes.

- ICOS data is used for satellite calibration/validation (Cal/Val) purposes and in synergy with satellite observations. ICOS started analysing existing as well as potential future applications:

  ICOS ecosystem data is used for satellite Cal/Val. For example, the clumping index derived with Digital Hemispherical Photography was compared to products of the MODerate Resolution Imaging Spectroradiometer (MODIS), the Deep Space Climate Observatory Earth Polychromatic Imaging Camera (DSCOVR EPIC) and the POLarization and Directionality of the Earth's Reflectance (POLDER). More potential for validating other satellite products, such as the normalised difference vegetation index (NDVI), biomass density, or surface temperature, with ICOS ecosystem data is there, but not fully exploited yet.

  ICOS atmospheric data is more difficult to use for Cal/Val purposes, since satellites mainly measure columnar values of gas concentrations, while ICOS provides near-surface data. However, there is potential for future applications, considering the new generation of satellite missions that will also provide height-resolved information. Moreover, ICOS GHG observations can be used as independent sources to check the performance of models assimilating satellite data and to detect biases.

ICOS ocean data includes ECVs like sea surface temperature, sea surface salinity and sea level pressure, which can be directly used for satellite

ICOS has demonstrated that data is used in a large number of research areas, including interdisciplinary fields.

Cal/Val. ICOS ocean carbon data may help in establishing continuity in data from current and future satellite observations. Furthermore, ICOS ocean carbon data may be used in the development and validation of new retrieval schemes for estimating ocean carbon fluxes from space-borne measurements.

EVALUATION OF KPI 23 Research areas where ICOS data is used

ICOS has demonstrated that data is used in a large number of research areas, including interdisciplinary fields. ICOS-related publications have been analysed with the help of Clarivate groups of Web of Science. Publications in 58 categories could be identified, with meteorology and atmospheric sciences being the most popular, followed by environmental sciences.

KPI 23 is indicative in nature and can be followed up in this sense in the future. The KPI is of moderate importance in the evaluation because the results of the survey might change only marginally over time.

EVALUATION OF KPI 25 Application of ICOS data in (globally leading) models

ICOS data is widely used in regional and global atmospheric and Earth system models. Data from all three domains are applied, e.g. for assimilation in inversion models, validation of model parameterisations and as input in Global Ocean Biogeochemical Models. It is concluded that ICOS is well connected to the modelling community and provides data according to the user needs.

KPI 25 will help monitor the use of ICOS data in models, and it is an important indicator for ICOS performance in the long term. It may become necessary to further develop this KPI in terms of a better specification of different model applications and data products needed for these purposes. Monitoring the development of new data products and services for model applications should also be considered.

EVALUATION OF KPI 26 Use of ICOS data in support of satellite observations

ICOS data is occasionally used in support of satellite observations, specifically for the validation of vegetation and ocean surface parameters. Few applications are known where ICOS data is applied in synergy with satellite observations for scientific investigations of biogeochemical processes and the carbon cycle. However, there is potential in all three ICOS domains to support satellite observations.

The new generation of satellite missions capable of providing GHG profile information will open up new opportunities for combining surface and space-borne measurements. KPI 26 will be helpful in monitoring such developments in the future, also in terms of new data products and services from ICOS.

CRITERION 3 ICOS data is used in educational tools and education activities

SUMMARY OF KEY FINDINGS

- The ICOS Summer School is organised regularly (about every second year) by the Carbon Portal and the University of Helsinki, targeting Doctor of Philosophy (PhD) students, postdocs and master's students. The number of participants was 32 in 2015 and 37 in 2017. The planned event in 2020 had to be postponed due to COVID-19.
- The Thematic Centres organise training events on the use of hardware and software tools, data processing and quality control. The annual sensor workshop organised by the OTC attracted 40 participants in 2018 and 2019 and about 25 during the virtual event in 2020.

There is potential in all three ICOS domains to support satellite observations.

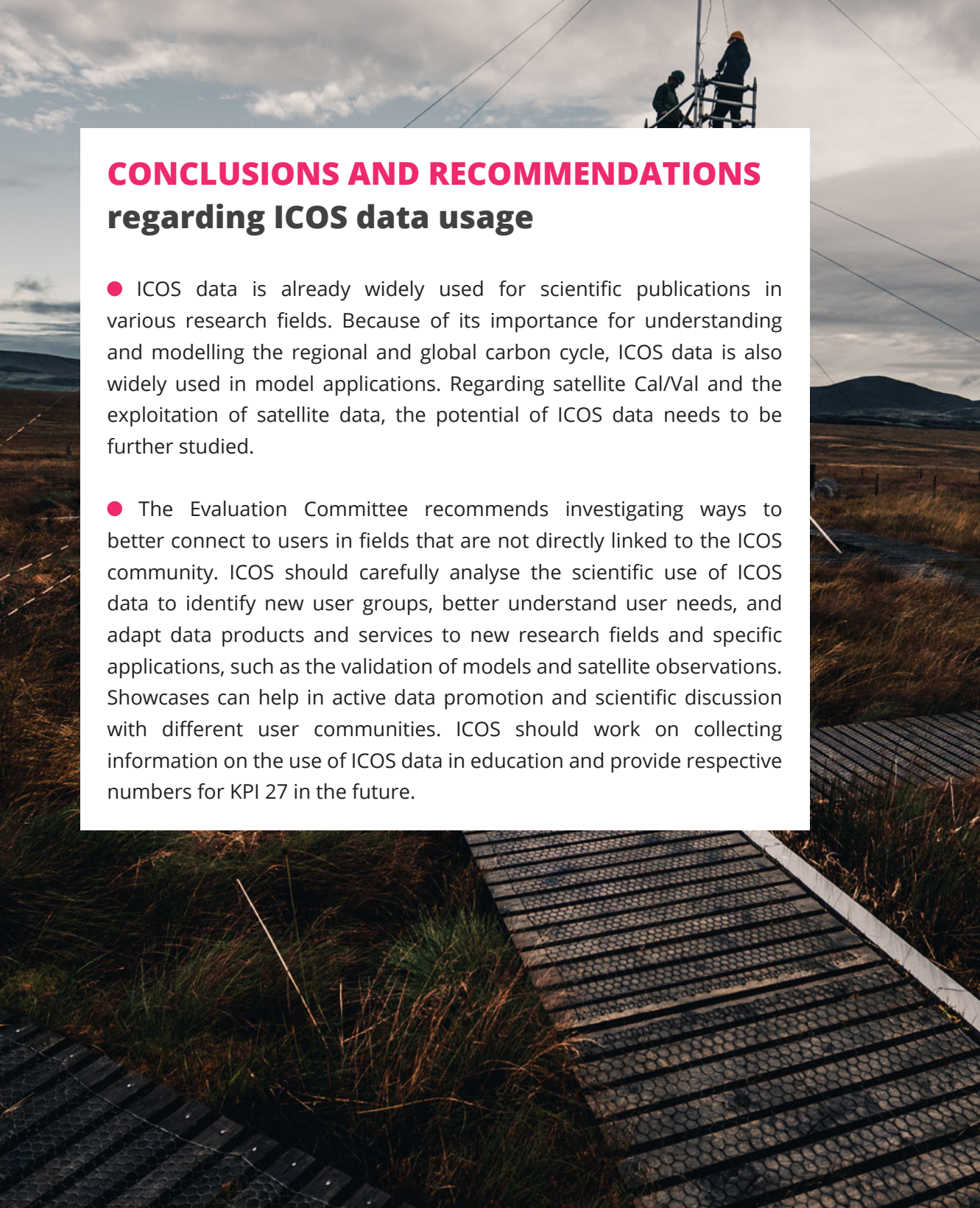
ICOS data is widely used in regional and global atmospheric and Earth system models.

- From a quick enquiry to station PIs, the evaluation compiled a non-exhaustive list of 22 PhD, 34 master's and 10 bachelor's theses in various fields of research.

EVALUATION OF KPI 27 Usage of ICOS data in educational tools and education activities

ICOS has provided evidence of the use of ICOS data in education, but only few tools, activities and participants are available. The information is too sparse for an in-depth evaluation.

KPI 27 shall be used in the future. It is necessary to establish a collection tool and an appropriate database of educational events and tools.



CONCLUSIONS AND RECOMMENDATIONS
regarding ICOS data usage

- ICOS data is already widely used for scientific publications in various research fields. Because of its importance for understanding and modelling the regional and global carbon cycle, ICOS data is also widely used in model applications. Regarding satellite Cal/Val and the exploitation of satellite data, the potential of ICOS data needs to be further studied.

- The Evaluation Committee recommends investigating ways to better connect to users in fields that are not directly linked to the ICOS community. ICOS should carefully analyse the scientific use of ICOS data to identify new user groups, better understand user needs, and adapt data products and services to new research fields and specific applications, such as the validation of models and satellite observations. Showcases can help in active data promotion and scientific discussion with different user communities. ICOS should work on collecting information on the use of ICOS data in education and provide respective numbers for KPI 27 in the future.

4.4 Active data promotion and meeting user/stakeholder expectations

Active data promotion and analysis of user and stakeholder expectations is important for ICOS to connect to its users, better understand user needs, improve ICOS services and to make the value and success of the RI visible to its stakeholders.

CRITERION 1 ICOS facilitates scientific initiatives successfully

SUMMARY OF KEY FINDINGS

- ICOS has started science-facilitating initiatives and completed a special issue on the European Summer Drought 2018 published by Philosophical Transactions B of the Royal Society (September 2020). The special issue contains 17 papers. More than 200 scientists participated in the research study.
- Presentations on the Summer Drought 2018 initiative were given at the ICOS Science Conference 2020 and at the European Geosciences Union (EGU) conferences in 2019 and 2020.
- New initiatives are in progress, focusing on the anomalous winter of 2019–2020 and COVID-19–related research.

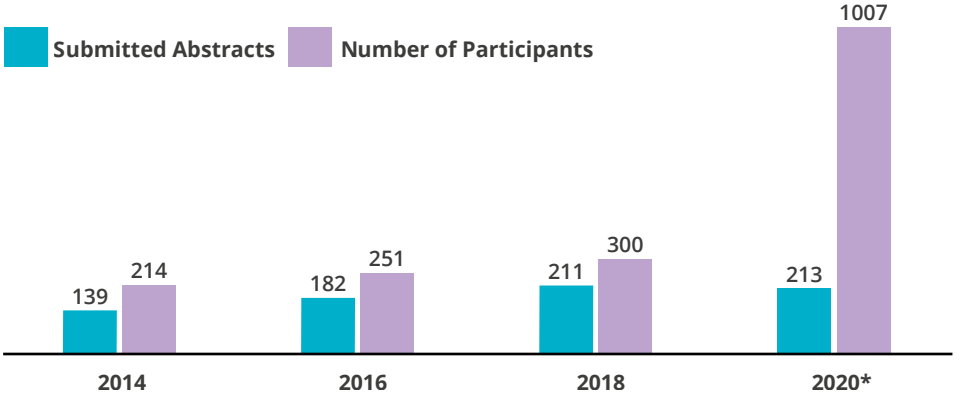
EVALUATION OF KPI 28 Facilitation of scientific initiatives

ICOS was very successful with its first science-facilitating initiative, which dealt with the European Summer Drought 2018 and resulted in 17 papers involving more than 200 scientists. ICOS is continuing to facilitate new scientific initiatives.

ICOS was very successful with its first science-facilitating initiative, which dealt with the European Summer Drought 2018 and resulted in 17 papers involving more than 200 scientists.

KPI 28 will help monitor the success of ICOS science-facilitating initiatives in the long term.

Figure 7. Submitted abstracts and number of participants in ICOS Science Conferences.



*The year 2020 conference was a free-of-charge online conference due to the Covid-19 related restrictions.

CRITERION 2 ICOS Science Conferences successfully enable scientific exchange

SUMMARY OF KEY FINDINGS

- The ICOS Science Conference has been organised every second year since 2014.
- The number of submitted abstracts increased from 139 in 2014 to 213 in 2020.
- The number of participants has grown from 214 in 2014 to 300 in 2018.
- The ICOS Science Conference 2020, offering free online participation, has attracted more than 1000 participants.
- Presentation themes and findings from the survey indicate that the ICOS Science Conference provides a view of the current state of science related to the carbon cycle and GHGs.

EVALUATION OF KPI 29 Enabling scientific exchange through ICOS Science Conferences

The ICOS Science Conferences are very attractive events. They are important for bringing the ICOS community together and providing a view of the current state of ICOS-related science. Both the number of participants and the number of submitted abstracts have grown steadily from 2014 to 2020.

KPI 29 helps monitor the attractiveness and success of the ICOS Science Conferences and should be applied in this way in the future.

CRITERION 3 Articles are published in online media/general media outlets, and the RI is present on social media

SUMMARY OF KEY FINDINGS

Stakeholder mapping to find out expectations:

- ICOS Head Office has started an exercise to study the needs and expectations of stakeholders more methodologically.
- This stakeholder mapping has produced an analysis of the most important stakeholder groups.
- The work was temporarily halted due to the challenges related to COVID-19.
- The next step is to use dialogue and service design methods to find out what the most important stakeholder groups need and expect of ICOS and its data (products).

Increasing the awareness of ICOS and its data among users and stakeholders:

- The combined number of unique views on the ICOS and Carbon Portal websites increased from 37 000 views in 2017 to 138 200 views in 2020. The two websites were merged in April 2020.
- ICOS is active on Twitter and Instagram. The number of Twitter followers has grown steadily by about 300 per year over the last four years. Instagram has been extensively used during a campaign in 2017–2018, leading to peak of followers in 2018 and a slight decrease since then.

- The number of ICOS-related publications in general online media has grown since 2016 and shows a peak in 2018, which is explained by a high number of public relations activities at the national level related to the successful labelling of many stations during that time. Recently, ICOS has reached a large potential audience via high-ranking media such as Medium (US, 116 million readers), La Repubblica (Italy, 25.9 million readers) and Wired UK (4.59 million readers).

EVALUATION OF KPI 30 Engagement with social and general media

ICOS is very active on social media, and well recognised there. The number of followers has steadily increased. The number of media appearances is high, with a peak in 2018. With attractive themes, ICOS demonstrated its ability to reach out to large audiences via high-ranking media.

KPI 30 is important for monitoring ICOS public relations and will help to evaluate respective efforts in the future. Activities and data should be reported annually.

With attractive themes, ICOS demonstrated its ability to reach out to large audiences via high-ranking media.

Figure 8. Media articles mentioning ICOS in 2016-2020

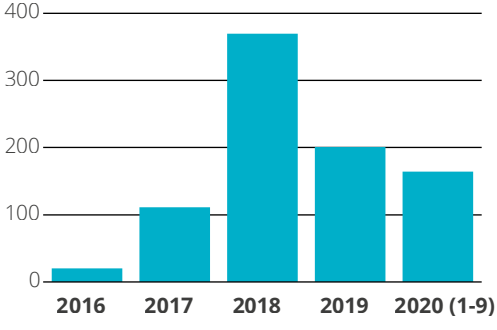
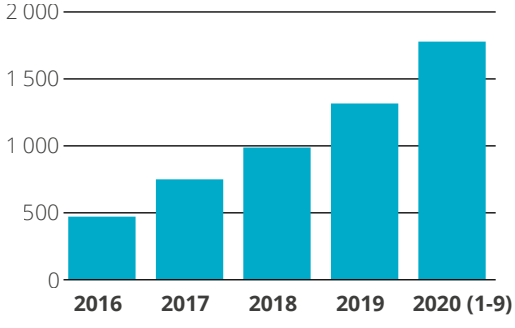


Figure 9. ICOS Twitter followers 2016-2020.



CONCLUSIONS AND RECOMMENDATIONS
regarding active data promotion and meeting user / stakeholder expectations

- ICOS has established various means for promoting ICOS data and meeting user and stakeholder expectations. The science-facilitating initiatives are an excellent way to advance ICOS's scientific excellence. Setting up new initiatives on different topics is strongly supported. These efforts will help ICOS to increase its visibility and strengthen external collaboration as well as internal engagement.

- The ICOS Science Conference is a success story as well. ICOS should continue to further develop the format of this conference series. Involving users, stakeholders and the private sector will help promote the development of new scientific applications, technologies and services based on ICOS data.

- Public relations efforts should be maintained and pushed continuously. Head Office should strive towards strong engagement of the entire ICOS community in communication and outreach activities.

4.5 Downstream private sector cooperation for ICOS data usage

Connections to the private sector are important for ICOS to increase the value of ICOS data and support the development of new services and solutions on climate change mitigation and adaptation.

CRITERION 1 ICOS engages in downstream projects with the private sector

SUMMARY OF KEY FINDINGS

- ICOS has been in contact with a few private companies working in the field of GHG measurements and data provision.
- ICOS invites the private sector to its Science Conferences where vendor expositions are organised. Participation has varied between two and 14 exhibitors and was at its lowest at the virtual conference in 2020.
- ICOS collaborates with manufacturers in testing new instruments and exchanging experiences. Instrument manufacturers use ICOS data to develop their equipment.
- ICOS Head Office participated in the Marine Autonomy and Technology Showcase (MATS) in 2018.
- ICOS OTC organised a Symposium on the North Atlantic Carbon Cycle in Southampton in March 2019. Connected to this, the ICOS Ocean MSA organised an Industry/Science Observing Forum with 26 participants to discuss collaboration with the private sector in the framework of the SOOP operations.

EVALUATION OF KPI 31 Engagement in downstream projects with the private sector

ICOS has established contacts with the private sector and offers opportunities for collaboration with manufacturers and service providers. Vendor expositions during the ICOS Science Conferences have been organised. Practical collaboration with private sector takes place in the Ocean domain

The use of ICOS data for technology and service development by the private sector has not yet been demonstrated.

to facilitate operation of the SOOP lines. However, specific projects together with industry partners and respective collaboration results have not been presented so far. The use of ICOS data for technology and service development by the private sector has not yet been demonstrated.

KPI 31 should be applied to monitor ICOS engagement with the private sector in the future. Reporting on the activities (e.g. the number of projects and the use of data) and documentation of the results (e.g. the number of publications and patents) should be established.

CONCLUSIONS AND RECOMMENDATIONS regarding downstream private sector cooperation for ICOS data usage

- ICOS has connections to the private sector and enables collaborations with manufacturers and private service providers. The RI should enhance these activities and facilitate common projects with industry partners. ICOS should analyse the needs of the private sector as a user group and identify fields and topics for collaboration. Establishing access opportunities to ICOS facilities as a new service, e.g. for instrument testing and calibration purposes, could be an option. Furthermore, needs and opportunities for the development of measurement standards and data products should be investigated.

CATEGORY 5
INTERNATIONAL COOPERATION

ICOS is responsible for providing policymakers with the best available scientific evidence as a basis for their decisions to address *'the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge'* (Paris Agreement).

Considering the nature of climate change, fulfilling the goal above requires a global reach, which is why **active international cooperation is a strategic priority of ICOS**. ICOS mission is to disseminate the knowledge generated based on the ICOS data by the scientists to the GHG policy- and decision-making organisations. This work relies on connections to and active participation in the global cooperation frameworks relevant to climate issues. It is therefore essential that ICOS data, products and services are fully integrated internationally.

During its development, ICOS has made substantial efforts to include its GHG data into the major global data integration initiatives. In this category, these efforts are analysed based on the above framework. This category investigates whether ICOS international cooperation has been implemented in agreement with the predefined tasks. Specifically, it assesses how well ICOS is integrated in European and global GHG information systems.

5.1 Estimation of the intensity of ICOS international cooperation

Evaluating the integration of ICOS into the global observing systems was based on an assessment of the range and level of cooperation with the main actors within the European and global GHG information system (Table 1). Three levels of interactions were identified. Level 1 signals informal discussions. Level 2 attests to concrete actions, joint participation in working groups and common projects. Level 3 bears witness to the existence of common products or formal agreements with partners.

CRITERION 1 Cooperation with the main actors of the European and global GHG information systems
CRITERION 2 Relevance for the global response to climate change

As part of the involvement in the organisations indicated in Table 1, additional activities nested within or branching out of them, include organisations such as the National Ecological Observatory Network (NEON), NOAA, the National Aeronautics and Space Administration (NASA), the Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure (eLTER RI), the Future Earth, EGU and the American Geophysical Union (AGU).

SUMMARY OF KEY FINDINGS

- ICOS has been involved in all the relevant international organisations concerning observations, research, assessment, policymaking, services and infrastructures. Within this wide range, ICOS is involved in different statuses and at different intensities.
- In the last five years, ICOS has become an observer organisation to the key global policymaking organisations, namely the United Nations Framework Convention on Climate Change (UNFCCC) and the Group on Earth Observations (GEO). This places ICOS at the strategic centre point between the international community of climate scientists and the fora where policymakers decide upon climate action.
- With its scientific expertise, ICOS thus plays the role of facilitator between the production of research data and its translation into actionable knowledge.

Table 3. Cooperation between ICOS and international organisations, and its intensity in scale from 1 (informal) to 3 (formal).

		Level 1	Level 2	Level 3	Status
Global Observations	CEOS	●			Participant
	FLUXNET			●	Provider
	GAW/IG3IS			●	Provider
	GCOS		●		Partner
	GOOS		●		Partner
	ObsPack			●	Provider
	SOCAT			●	Provider
	WMO		●		Partner
Global Research	WCRP	●			Participant
Global Assessment	IPCC	●			Observer
Global Policymaking	GEO			●	Observer
	UNFCCC			●	Observer
Climate Services	Copernicus		●		Partner
	GFCS	●			Participant
Other European & International RIs	ENVRI Community			●	Member
	GERI			●	Member

EVALUATION OF KPI 32 Level of cooperation with the main actors of the European & global GHG information systems

The analysis noted above indicates that ICOS is involved in over 16 international organisations, and in the majority of cases at Level 3 intensity (while some involvements at Level 1 and 2 are justified). Based on this KPI, ICOS integration into global observing systems is therefore considered highly favourable.

ICOS integration into global observing systems is considered highly favourable.

ICOS could enhance its role and contribution by further developing the carbon flux partitioning to its anthropogenic component, increasing contributions toward providing national carbon accountings and evidence of adaptations.

EVALUATION OF KPI 33 Relevance in the global response to climate change

Some of the organisations in which ICOS is involved are clearly engaged in developing the response to climate change at different levels. This includes the 'Global Assessment' part in Table 1, such as in the case of the Intergovernmental Panel on Climate Change (IPCC) and the World Climate Research Programme (WCRP). However, addressing this KPI should be based, in particular, on data and reports provided directly to policy-oriented organisations, such as UNFCCC and GEO. It should similarly be supported with dynamic adjustments to the ongoing developments in the climate change policy arena. The survey results, the comments added by participants, and the follow-up discussions with international stakeholders pointed out that ICOS could enhance its role and contribution by further developing the carbon flux partitioning to its 'anthropogenic component', increasing contributions toward providing 'national carbon accountings' and 'evidence of adaptations'.

CONCLUSIONS AND RECOMMENDATIONS
regarding estimation of the intensity of ICOS international cooperation

- ICOS is commended for having been successful in getting involved in most of the key international organisations both within Europe and globally, including key policymaking agencies. The complexity of the international system results in some of the activities being nested within organisations, such as those listed in Table 2.

- We noted that our current evaluation may underestimate ICOS international exposure and cooperation, as some of ICOS activities and representatives have significant contributions to programmes and projects that are less exposed when only the umbrella-type organisations are considered (Table 2). The review process also helped to identify specific topics in which ICOS can enhance its 'relevance in the global response to climate change'.

5.2 The individual level of ICOS involvement in international cooperation

Another way to evaluate the integration of ICOS at the global level is to monitor the participation in events of regional or global importance.

CRITERION 1 Participation in events of regional or global relevance

Table 2 gives an overview of the main occurrences over the last five years. It is important to mention that not all participation modes are equivalent. However, even if organising an ICOS side event has more impact, it is not possible in every framework.

In addition to taking an active role in international organisations, ICOS members participated and presented results at a range of international events, such as conferences, workshops and panels. Between 2015 and early 2020, the Evaluation Committee noted ICOS participation in 20 international events across Europe, Africa, North America, Australia and Asia. At these events ICOS was represented mainly by 14 ICOS official representatives, scientists and other personnel.

ICOS provides knowledge to agencies and international organisations that provide or define GHG inventories.

Table 4. Activities of individuals from the ICOS community involved in international organisations.

	Organisation	ICOS representation*
Global Observations	FLUXNET	ETC
	GAW/IG3IS	CP, ATC, CAL, A-MSA
	GCOS	HO
	GOOS/IOCCP	OTC
	ObsPack	CP, ATC
	SOCAT	OTC, O-MSA
	WMO	HO, ATC, OTC
	WCRP	HO
Global Research	IPCC	HO
Global Assessment	GEO	HO
Global Policymaking	UNFCCC	HO
Copernicus	HO, CP, OTC, ATC	
Climate Services	GFCS	HO
ENVRI Community		HO, CP, ETC, ATC, OTC
Other European & International RIs and organisations	GERI	HO, CP, ETC
NEON	CP, ETC	
	NOAA	CP, CAL, OTC
	NASA	HO
	NIST, BIPM	CP, CAL
	Others	OTC

**HO = ICOS Head Office*
CP = Carbon Portal
ATC, ETC and OTC = Thematic Centres for Atmosphere, Ecosystem and Ocean
A-MSA and O-MSA = Monitoring Station Assemblies for Atmosphere and Ocean
CAL = Central Analytical Laboratory

SUMMARY OF KEY FINDINGS

- Based on our analysis, at least 14 ICOS community members (scientists and administrators) participate in active roles in key international organisations. These roles range from members of panels, chairs of committees, members of scientific committees, coordinators, and so on.
- ICOS is represented at international events around the globe.
- This extensive and active participation further strengthens the conclusions of the above section, reflecting strong and active international cooperation on different levels.

EVALUATION OF KPI 34 Participation in events of regional or global relevance

This KPI is supported by at least 14 ICOS community members playing an active role in a wide range of international organisations; at least six ICOS representatives participated in 20 international events between 2015 and early 2020, and in particular in organising four well-attended international open science conferences, and organising ICOS sessions at major international conferences, such as AGU and EGU, all of which help disseminate ICOS information globally. This KPI is also supported by the strong response to the international surveys that indicated that ICOS provides knowledge to 'agencies and international organisations that provide or define GHG inventories'.

We also note, as in the last section (5.1), that if there is an evaluation of the impact of ICOS in this area of activity, one should consider evaluating the global carbon cycle and GHG observations system support for climate action. Progress towards impact in this area is mainly supported, as noted above, by the wide range of ICOS presentations in the past five years as well as the strong response in the international surveys indicating ICOS's role in providing knowledge to both scientists and decision makers. While data dissemination is evaluated in other categories – particularly category 4 - it is also important to specifically note the international component of ICOS data dissemination.

CONCLUSIONS AND RECOMMENDATIONS

regarding the individual level of ICOS involvement in international cooperation

- In addition to membership and participation in international organisation noted in section 5.1 above, the Evaluation Committee analysis also indicated that this is based on the participation of individual ICOS members in active roles, and in disseminating ICOS information across a wide range of international events. These findings reflect the build-up of a strong international cooperation component in ICOS over the past five years.

- Based on these analyses and the results of the surveys, the Evaluation Committee suggests that ICOS increases its efforts to ensure that community members clearly emphasise their ICOS link at international organisations and events. The Evaluation Committee also suggests to further expand the participation of ICOS members at all levels to represent ICOS at both international organisations and special events.

5.3 ICOS international cooperation in the eyes of the stakeholders

While the sections above analysed the data regarding ICOS international cooperation, extending this information relied on the input and impression of stakeholders in Europe and internationally. Two criteria were used in the evaluation of this aspect of international cooperation, each with a KPI.

CRITERION 1 Common observational sites with other RIs at country level
CRITERION 2 Formal agreements (Memoranda of Understanding, MoUs) with other RIs or organisations

In this respect, the justification for ICOS operation is confirmed: all respondents strongly agree that ICOS is relevant for the global response to climate change. There is also strong agreement that ICOS is doing well in terms of the provision of observational data, standardisation of protocols and data curation, as well as in terms of quality control.

The international stakeholders consulted in the framework of this evaluation also helped to identify key areas where ICOS is developing, and where such efforts should continue. This includes international cooperation towards the global standardisation of observations and promoting FAIR principles of observational data globally.

The expansion of the ICOS network to underrepresented regions of the world has received much attention at ICOS, as is now reflected in the publication of Nickless et al., [7] which reports on a large project that provides a comprehensive vision for the GHG observation network in Africa. Such expansion to additional geographical regions and to climate 'hotspots', and to sites where the co-location of monitoring platforms is established, is

7 Nickless et al. 2020 Greenhouse gas observation network design for Africa. Tellus B: Chemical and Physical Met. *Doi.org/10.1080/16000889.2020.1824486*

highly desirable. This will also require recognition of economic realities in other countries that cannot attain ICOS standards: therefore, ICOS should offer alternatives for cooperation, data sharing and integration.

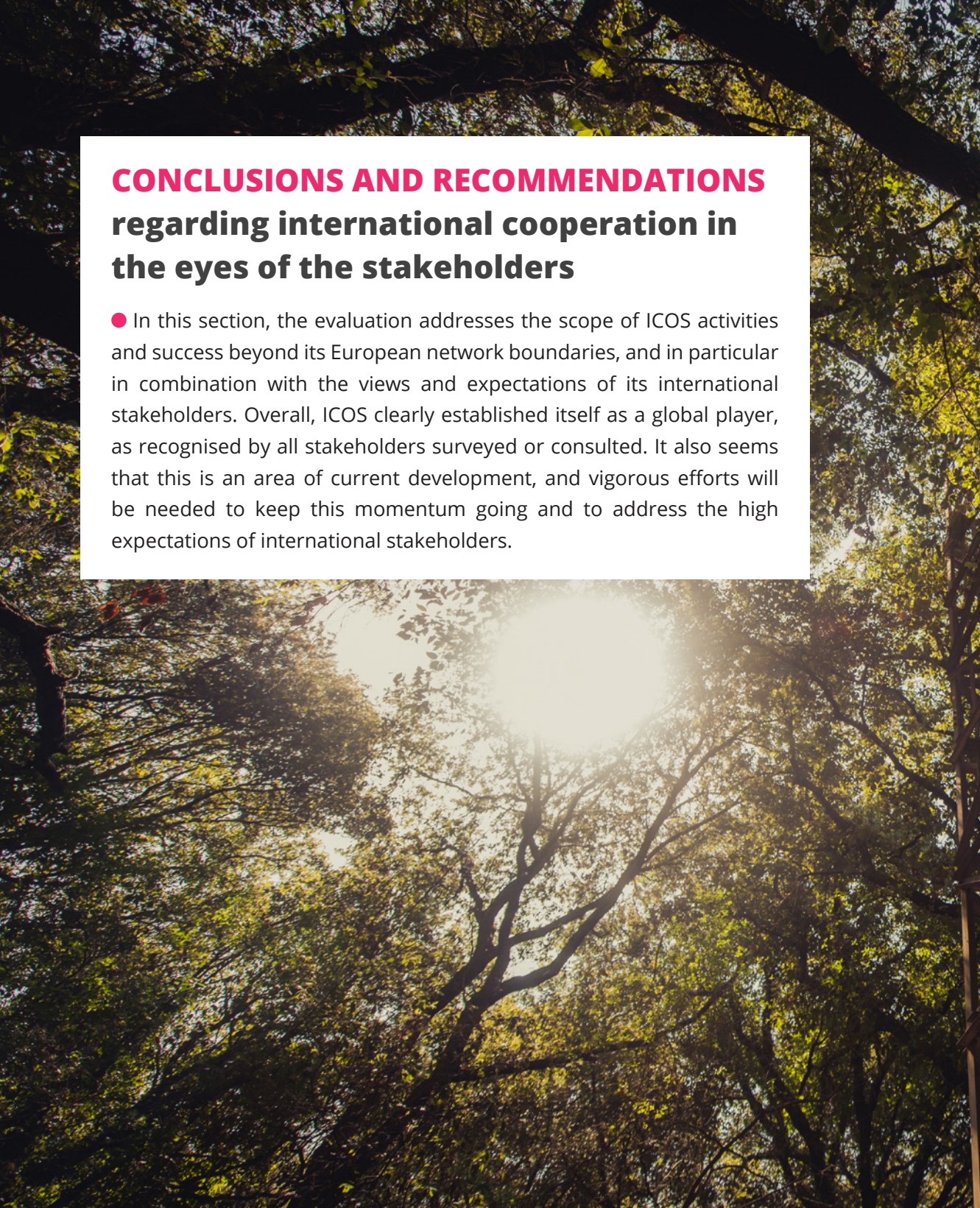
Collectively, what ICOS is trying to do goes beyond its European geo-political boundaries. **International agreements** also place the ICOS efforts in a global context. These interactions often require more formalised relationships, such as based on MoUs. The Evaluation Committee is not aware of a clear policy in this respect, but there are activities underway in this direction.

EVALUATION OF KPI 35 Number of common observational sites with other RIs at country level

Evaluation of this KPI indicated that this is an active area of development at ICOS that should continue to be vigorously pursued. Survey results show support for the proposition that more effort is needed in this area, though no data about the number of common observational sites was available at the time of the evaluation. It is also an area in which expectations of international stakeholders are high, as reflected in the international surveys conducted within the evaluation.

EVALUATION OF KPI 36 Number of formal agreements (MoUs) with other RIs or organisations

The evaluation of this KPI indicates that while there may not be a clear policy regarding MoUs, ICOS is currently engaged with several MoUs, such as in the establishment of the Global Ecological Research Infrastructure (GERI) and for the Environmental Research Infrastructure (ENVRI) community, and an MoU is in place with NOAA and the Pacific Marine Environmental Laboratory (PMEL) working on SOCAT.



CONCLUSIONS AND RECOMMENDATIONS
regarding international cooperation in the eyes of the stakeholders

In this section, the evaluation addresses the scope of ICOS activities and success beyond its European network boundaries, and in particular in combination with the views and expectations of its international stakeholders. Overall, ICOS clearly established itself as a global player, as recognised by all stakeholders surveyed or consulted. It also seems that this is an area of current development, and vigorous efforts will be needed to keep this momentum going and to address the high expectations of international stakeholders.

CONCLUSIONS

1. Principal findings and recommendations for each category

1 MANAGEMENT

- **General management** has been successfully established during the implementation phase, but now that the RI is becoming fully operational, thought should be given to the evolution of the organisation and its processes. The survey provides pointers about delegation of responsibility and decision making, and high-level meetings (e.g. of the General Assembly) that would benefit from being able to discuss strategic issues in greater depth. A review should also be made of the decision-making processes with respect to delegating more to the people responsible for producing the data. Such a structure might be improved by including Central Facilities into the ERIC.

- **Operational management.** Robust, high-quality and efficient operations have been set up in a remarkably short period of time, with Level 2 and NRT (Level 1) data channelled very effectively through the Carbon Portal. However, it is recommended that further study is needed on whether support and resourcing for measurement stations undergoing labelling is sufficient, e.g. by creating a task force that helps them to label the stations. A prioritised plan should also be considered to engage with new and existing members to establish sufficient range and density of measurement stations to ensure the temporal and spatial coverage required to fulfil the ICOS mandate.

  A medium- to long-term strategy and a plan are needed for maintenance and replacement of infrastructure and instrumentation to ensure that it remains at least competitive, as well as for the adoption of new technology.

● **Data life cycle.** The ICOS data life cycle has been set up very robustly and effectively in a remarkably short period of time. A wider range of data services needs to be developed and catalogued in consultation with the user community.

2 FINANCIAL MANAGEMENT

● **Core funding.** ICOS financial management with regard to core funding is sound, passing annual audits with no critical remarks, remaining stable in recent years, with a well-structured plan. The equity ratio was also found to be healthy. However – and not surprisingly for an organisation of ICOS's complexity and with so many member countries members, each with their own way to fund the various components of the ICOS network – there are challenges that will require further work, much of which appears to be already in hand. The following are noted in particular:

- A closer follow-up of discrepancies between the budget and expenditure is desirable.
- Financial information should be made more available and accessible, perhaps through development of the ICOS web page.
- The Financial Committee should investigate setting up a contingency fund to handle unspent funds and propose the possible size of that contingency fund.
- In order for the equity ratio to be useful to ICOS, a benchmark value should be provided, and a strategic plan should be drawn up if the equity ratio deviates from this plan.
- Several of the KPIs would benefit from the establishment of benchmark values in the future to aid management planning.

● **Project funding.** There is already significant activity in seeking project funding, but there is much potential to build on it and improve on reporting. As for the other finance-related KPIs, a quantifiable KPI with a benchmark value would be useful for project funding.

3 INTERNAL ENGAGEMENT AND INTEGRATION

● **The internal engagement** of ICOS is solid and there is keen participation in most activities. However, the broad structure of ICOS calls for support to further improve internal scientific and technical collaboration, especially with more collective research initiatives across domains. Even if these aspects are continuously considered by Head Office, it would improve the feeling of internal integration if they are assessed and the result is reported to the ICOS community, for example during the Science Conference.

● **The internal integration** of ICOS should be looked at to better involve the different bodies in an equal way and thus potentially improve their collaboration. A further result might be equal contribution by the different RI bodies to ICOS tasks, and common and equal participation in projects. As this is a central part of better communication and collaboration across domains, it has to be assessed in more detail.

4 DATA AND USER EXPECTATIONS

● **A priori design.** ICOS has successfully implemented GHG data services that agree with international standards and comply with user and stakeholder expectations. ICOS should continue working on the codesign of standards at international level and take a leading role in future developments, design and standardisation efforts for the global GHG observing system.

- **Data download.** The Carbon Portal enables user-friendly access to qualified data, data products and services. Tracking tools have been successfully implemented and versatile data download statistics are provided. Increasing user interest for the first two years of data provision has been demonstrated for all domains. The great challenge for ICOS is that data is also available from other global repositories, which do not offer tracking possibilities. Therefore, ICOS should actively work with international partner organisations and promote the general use of PID and DOI.

- **ICOS data usage.** At the end of the implementation phase, ICOS has demonstrated that its data, data products and data services are of high value and are widely used across different scientific fields, which is indicated, e.g. by the large and steadily increasing number of scientific publications and citations. Data is widely used in model applications, but not so much in support of satellite remote sensing. Identifying and connecting to new user groups with the aim of adapting to user needs and widen service provision should be a focus in the future. ICOS should also enhance the use of its data for educational purposes and implement respective monitoring tools.

- The ICOS Science Conference and science-facilitating initiatives are successful means for **active data promotion**. These activities increase the visibility of ICOS and strengthen external collaboration as well as internal engagement, and thus should be forcefully pursued. ICOS Head Office is very active in public relations and has increased its efforts for analysing **user and stakeholder expectations**. This work needs to be continued with a view of new challenges and opportunities and by engaging the entire ICOS community.

● ICOS has prepared the ground to enable **downstream private sector cooperation for ICOS data usage** and offers opportunities for collaboration with manufacturers and service providers. As a next step, ICOS should enhance its efforts to facilitate dedicated projects with industry partners and promote the use of ICOS data for technology and service development by the private sector.

● The Evaluation Committee fully supports the ICOS Strategy (approved by ICOS General Assembly in May 2019) to further develop its services based on a steady dialogue with users and stakeholders. Continuous monitoring and development of the RI is essential for maintaining scientific excellence and enabling frontline research. User needs regarding new data products and services, advanced technologies and additional opportunities such as physical and remote access to RI facilities should be investigated. ICOS should also continue to work together with other environmental RIs to establish an attractive service portfolio for scientists, policymakers and the general public in Europe and beyond.

5 INTERNATIONAL COOPERATION

● After five years of development, ICOS has established itself as a global power in the GHG and climate change arena. It is formally involved in all the key international organisations, often playing a leading role, and supports observational networks beyond Europe. ICOS is also clearly involved in key global assessment and policymaking forums, enhancing its international influence.

● ICOS should consider the following points in this area of activity as it continues to evolve.

- Develop policy regarding MoUs with international organisations

• Establish wider formal recognition of the people representing ICOS on international bodies to give ICOS activity greater recognition.
• Respond to the increasing political and societal demand to monitor and quantify the anthropogenic component, achieving national-scale carbon accounting, and providing evidence for adaptation.
• Improve the interface between the scientific perspective of a science-based network such as ICOS and the needs of emission reports, inventories or national adaptation documents, such as those used by UNFCCC, which currently relies more directly on GCOS.
• While ICOS strives to lead on methods of standardisation and labelling, it should also find alternatives to accommodate and interact with researchers in countries (in Europe and beyond), that are unable to attain these demanding benchmarks but can greatly contribute to the ICOS agenda and vision.

2. Development of the KPIs

The KPIs used in this evaluation have been developed throughout the process, some after the data had been gathered and surveys completed, following ongoing reflection by ICOS ERIC and the Evaluation Committee about what might provide the most useful and appropriate input for ICOS management in the future. Some of these KPIs – for example KPI 1 – are specific to the implementation period, some will continue to be used, perhaps in a form that will need to evolve, and some have yet to be defined in anticipation of future strategic directions and activities. The Evaluation Committee recommends that ICOS ERIC reviews the status of the KPIs in a few years' time and presents a report to the General Assembly with suggestions on how they should evolve. The committee anticipates that a key development will be the introduction of benchmark values for many of them.

3. The evaluation process

The Evaluation Committee found the evaluation process to be very challenging, requiring the whole evaluation concept that the General Assembly had outlined to be developed in much greater detail with ICOS ERIC. The committee was also involved in the development of KPIs, the list of items to be gathered as evidence, devising and implementing surveys and even developing the nature of the reporting documentation and evaluation meeting. Some of this was a consequence of the pioneering nature of the process, concerning the evaluation of a distributed infrastructure for the first time. However, with the benefit of hindsight, it would have been more efficient and effective for the Evaluation Committee if all the material to be assessed, together with the definition of all processes and documents, had been in place before it started the evaluation, and the primary sources of evidence – the ICOS ERIC report, with the survey results – all complete before the first evaluation meeting. This would have required a longer period of development of the evaluation concept with the General Assembly. Nevertheless, the Evaluation Committee believes it was able to maintain sufficient distance from ICOS ERIC to be able to provide a fully independent view and did find the process interesting and rewarding, which should provide a useful basis for future reviews.

4. Other general points

The surveys revealed a wealth of data that should be used to develop a prioritised action plan, including further exploration of issues that are not yet completely clear. Such surveys should be conducted periodically to assess whether actions undertaken are effective and the key outcomes and proposed actions reported to the ICOS General Assembly.

Acknowledgements

The Evaluation Committee would like to thank many of the staff members at ICOS ERIC for the work they put into developing and implementing surveys, as well as gathering and presenting the resulting data. They would also like to thank them for their input into the development of criteria and KPIs and collaboration in finding a common structure for their respective reports. Particular thanks go to: Katri Ahlgren, Inka Hella, Liisa Ikonen, Shawnie Kruskopf, Werner Kutsch, Anne Malm, Evi-Carita Riikonen, Emmanuel Salmon, Elena Saltikoff and Alex Vermeulen. The Evaluation Committee would also like to thank those who participated actively in the Evaluation Meeting of 21–22 October 2020, and to the Chair of the General Assembly, Jean-Marie Flaud.

The Evaluation Committee fully supports the ICOS Strategy to further develop its services based on a steady dialogue with users and stakeholders.

APPENDICES

APPENDIX 1
Abbreviations and initialisations

Abbreviation	Full name	Definition
ATC *https://icos-atc.lsce.ipsl.fr/*	Atmosphere Thematic Centre	Part of ICOS
AGU *https://www.agu.org/*	American Geophysical Union	An international not-for-profit association; conference organiser
BIPM *https://www.bipm.org/*	Bureau International des Poids et Mesures (FR)	National metrology institute
CAL *https://www.icos-cal.eu/*	Central Analytical Laboratories	Part of ICOS
CEOS *https://ceos.org/*	Committee on Earth Observation Satellites	Global satellite organisation
CF	Central Facility	Body in ICOS organisation
CP *https://www.icos-cp.eu/observations/carbon-portal*	Carbon Portal	Part of ICOS
CO_2	Carbon dioxide	Greenhouse gas
DOI	Digital Object Identifier	A system of identifiers applied to ICOS data to increase tracking of the data to its producer
DSCOVR EPIC *https://epic.gsfc.nasa.gov/*	Deep Space Climate Observatory Earth Polychromatic Imaging Camera	A NOAA Satellite instrument presented in the ICOS Science Conference
EGU *https://www.egu.eu/*	European Geosciences Union	An international not-for-profit association; conference organiser
eLTER RI *https://www.lter-europe.net/*	Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure	Another RI
ENVRI *https://envri.eu/*	European Environmental Research Infrastructures	Cooperation between RIs
EOSC *https://eosc-portal.eu/*	European Open Science Cloud	
EOV	Essential Ocean Variables by Global Ocean Observing System (GOOS)	
ERIC	European Research Infrastructure Consortium	Community legal framework established by the European Union

Abbreviation	Full name	Definition
ETC *http://www.icos-etc.eu/icos/*	Ecosystem Thematic Centre	Part of ICOS
EUDAT *https://eudat.eu/*	European Data Infrastructure	Infrastructure of integrated data services and resources supporting research in Europe
EUROCOM *https://eurocom.icos-cp.eu/*	European atmospheric transport inversion comparison	A collaboration project between seven European research institutes
FAIR	FAIR principles: Findable, Accessible, Interoperable, Reusable	Principles applied, e.g. in ICOS Carbon Portal
FLUXNET *https://fluxnet.org/*	1) The data portal and 2) measurement site network	
GA	General Assembly	Body of ICOS, representing member countries, (usually the ministries funding ICOS)
GAW *https://community.wmo.int/activity-areas/gaw*	Global Atmosphere Watch	WMO programme
GCOS *https://gcos.wmo.int/*	Global Climate Observing System	Activity co-sponsored by WMO, ICOS-UNESCO, UNEP and ISC
GEO *https://earthobservations.org*	Group on Earth Observations	Intergovernmental organisation
GEOSS *https://earthobservations.org/geoss.php*	Global Earth Observation System of Systems	
GERI	Global Ecological Research Infrastructure	Cooperation framework between RIs
GFCS *https://gfcs.wmo.int/*	Global Framework for Climate Services	WMO coordination framework
GHG	Greenhouse gases (CO_2, NH_4, N_20, water vapor)	
GOOS *https://www.goosocean.org/*	Global Ocean Observing System	
ICOS ERIC	Integrated Carbon Observation System European Research Infrastructure Consortium	
ICOS-INWIRE	ICOS improved sensors, network and interoperability for GMES	ICOS project
ICOS PPP	ICOS Preparatory Phase Project	
IG3IS *https://public.wmo.int/en/resources/bulletin/integrated-global-greenhouse-gas-information-system-ig3is*	Integrated Global Greenhouse Gas Information System	WMO activity

Abbreviation	Full name	Definition
InGOS	Integrated non-CO_2 Greenhouse Gas Observing System	A past ICOS EU project
IOCCP *https://www.ioccp.org/*	International Ocean Carbon Coordination Project	
IPCC *https://www.ipcc.ch/*	Intergovernmental Panel on Climate Change	
ISC *https://council.science/*	International Science Council	International non-for-profit organisation
KPI	Key Performance Indicator	
MATS	Marine Autonomy and Technology Showcase	Annual conference in the UK
MODIS	Moderate resolution Imaging Spectroradiometer	A research method presented in the ICOS Science Conference
MoU	Memorandum of Understanding	
MSA	Monitoring Stations Assembly	Body of ICOS; representing the PIs of one domain
NASA *https://www.nasa.gov/*	National Aeronautics and Space Administration (USA)	
NDVI	Normalised Difference Vegetation Index	
NEON *https://www.neonscience.org/*	National Ecological Observatory Network (USA)	
NIST *https://www.nist.gov/*	National Institute of Standards and Technology (USA)	National metrology institute
NOAA *https://www.noaa.gov/*	National Oceanic and Atmospheric Administration (USA)	
NRT	Near-real time	Describing data that is quickly available but only lightly processed
ObsPack *https://www.esrl.noaa.gov/gmd/ccgg/obspack/*	Observation Package	Data delivery channel of NOAA in the USA
OTC *https://otc.icos-cp.eu/*	Ocean Thematic Centre	Part of ICOS
PI	Principal Investigator	Scientist in charge of an ICOS station
PID	Personal Identifier	A subset of personally identifiable information (PII) data elements, which identify a unique individual and can permit another person to 'assume' that individual's identity without their knowledge or consent.

Abbreviation	Full name	Definition
PMEL *https://www.pmel.noaa.gov/*	Pacific Marine Environmental Laboratory	
POLDER	Polarisation and Directionality of the Earth's Reflectance	A research method, presented e.g. in the ICOS Science Conference
QC	Quality control	
RI	Research infrastructure	Such as ICOS RI
RI COM	Research Infrastructure Committee	Body of ICOS, representing all Thematic Centres, MSAs and Head Office
RINGO *https://www.icos-cp.eu/observations/projects/ringo*	Readiness of ICOS for Necessities of Integrated Global Observations	EU-funded project 2017–2020.
SOCAT *https://www.socat.info/*	Surface Ocean CO_2 Atlas	Synthesis activity for quality-controlled, surface ocean fCO_2 (fugacity of carbon dioxide) observations by the international marine carbon research community (>100 contributors)
SOOP	Ship of Opportunity	ICOS Ocean stations that are either research vessels or commercial ships operating on regular, repeated shipping routes on the European shelf and marginal seas and those of cargo vessels on open ocean routes
TC	Thematic Centre	
TRENDY	Trends in net land-atmosphere carbon exchange	Experiment in 1980–2010
UNFCCC *https://unfccc.int/*	United Nations Framework Convention on Climate Change	
WCRP *https://www.wcrp-climate.org/*	World Climate Research Programme	
WDCGG *https://gaw.kishou.go.jp*	World Data Centre for greenhouse gases	
WMO *https://public.wmo.int/en*	World Meteorological Organization	Specialised agency of the United Nations

APPENDIX 2
Report on KPI 10, Subcategory 1.3: Data compliance with FAIR principles

This report summarises an analysis of the RINGO Deliverable D5.5 titled ICOS improved data life cycle of July 2020 in light of the FAIR principles. The deliverable describes the latest state of the ICOS data life cycle and was thus used as a basis to assess how well the ICOS data life cycle meets the FAIR Data Principles. For this analysis, we extracted from the deliverable text statements as evidence for FAIR sub-principle implementation. Table 1 (Appendix) lists all extracted statements and organises them per FAIR sub-principle.

OVERALL ASSESSMENT. The analysis suggests that ICOS meets the FAIR principles to a high degree. Relevant statements can be found for all sub-principles except for A2: Metadata should be accessible even when the data is no longer available, and I2: (Meta)data uses vocabularies that follow the FAIR principles. Regarding A2, while we did not find matching statements, this requirement is implicitly satisfied for data that is persistently identified (in particular DOI-based identification) to the extent of the metadata shared with, in this case, DataCite. Indeed, metadata shared upon minting such PIDs remains accessible independently of ICOS. Regarding I2, it is clear that ICOS and, specifically, the Carbon Portal (CP) make considerable use of technologies (e.g. Web Ontology Language) needed to meet the FAIR sub-principles on Interoperability. However, D5.5 remains silent on the vocabularies used to describe data and metadata; thus it was unable to determine whether these vocabularies follow the FAIR principles.

SPECIFIC COMMENTS

- We suggest that five principles out of 11 (discarding A2 and I2 for which we

did not find evidence) are implemented excellently. These principles are F2, F4, A1.1, A1.2 and R1.3.

- For F1 it is clear that data is assigned PIDs, but we found no evidence of assigning PIDs to metadata.
- The analysis suggests implementation of sub-principle F3, but we could not determine whether the chosen approach is explicit, i.e. whether or not machines can discover the identifier of the data in metadata. For this to be true, the chosen approach must follow a widely agreed community standard for how to include the identifier of the data in metadata. One possibility may be https://schema.org/distribution.
- Principle I1 is met excellently for metadata. However, we did not find evidence of sub-principle implementation for data. Granted, what exactly is a 'formal, accessible, shared, and broadly applicable language for knowledge representation' for data is not as obvious as for metadata. Even for data that in principle has a suitable candidate language (e.g. sensor data with the Semantic Sensor Network Ontology or tabular data with the RDF Data Cube Vocabulary), it remains unclear whether these approaches scale to the size of an RI such as ICOS. Still, it is beneficial for data reuse if the data is indeed encoded using a language that can be read programmatically and is well and openly documented so that anyone with the required programming skills can develop software to access the data (also binary). A proprietary (binary) language would not meet the requirements.
- We found little evidence in support of I3. On one hand, this sub-principle requires implementation for both data and metadata. Hence, both data and metadata should include qualified references to other (meta)data. Qualified references are references that are precise (semantically narrow). Hence, the reference isParentOf between a person and a child is more qualified than the reference isRelatedTo. We found one statement that suggests that ICOS metadata will be mapped to other community and worldwide standards.
- Principle R1.1 is implemented for data, but we found no evidence for principle implementation for metadata. Just as with data, metadata need to

be released with a clear and accessible usage licence. It may be that the ICOS data usage licence is applicable to both data and metadata (since metadata is in fact data).

- Principle R1.2 has reasonable implementation for data, but we found no evidence for principle implementation for metadata. Just as with data, metadata is generated and processed and should have associate provenance information (which is thus metadata about metadata). The evidence found seems to suggest that the implementation of the principle for data could also be further improved.

ACTION POINTS

- Determine whether metadata, both generic metadata registered upon minting a PID as well as domain-specific metadata primarily available through the CP, are accessible even when the data is no longer available (A2).
- Determine which formats are used to encode data and determine whether these meet the requirements of being formal, accessible, shared and broadly applicable (I1).
- Determine which vocabularies are used by the CP and ICOS more generally in order to determine their conformance to the FAIR principles (I2).
- Determine which references between ICOS data and metadata to other (meta)data are used and determine whether or not they are qualified references, e.g. properties of a vocabulary that is used by the community to create qualified references between (meta)data (I3).
- Determine whether metadata is released with a clear and accessible data usage licence (R1.1).
- Determine whether provenance information is associated with metadata and consider to further improve the implementation of provenance tracking for (meta)data in ICOS (R1.2).

Table 1. Statements extracted from RINGO Deliverable D5.5 as evidence for FAIR sub-principle implementation in the ICOS data life cycle. Where necessary, because the sub-principle addresses both data and metadata, we highlight these words in statements in bold font. We underline the words that refer to technologies relevant to the sub-principle and are thus evidence for implementation. The sub-principles that are in our opinion met excellently are highlighted in italic font. Corresponding evidence is given in numerous relevant implementations underlined in statements.

PRINCIPLE	HOW ADDRESSED
F1: (Meta)data is assigned globally unique and persistent identifiers	All data is identified. Persistent identification of all data objects. ICOS has chosen to primarily work with [identifiers] built on the **Handle system**, and DOIs (Digital Object Identifiers) from **DataCite**. CP is responsible for providing a digital object identifier. NRT data [...] is minted PIDs (and DOIs) through the Carbon Portal. DOIs will be assigned to all published data objects (NRT, Level 2 and Level 3 – 'citable data' [...]), since these are the ones most likely to be referred to, or cited, in scientific contexts. 'Raw data' or 'referable data' [...] will [...] be assigned Handle PIDs. The ICOS data can be easily identified using the ICOS PIDs and the independently minted Handle PIDs that EUDAT minted for the data files using the B2Handle system.
F2: Data is described with rich metadata	The requirement is to submit at least one full year of data that must include a **set of key variables** with full description and meta-information, with the acceptance of the ICOS data policy. (Metadata) that describes the data and the **processing steps (curation) applied to the data**, so that the whole chain of provenance is traceable, transparent and reproducible. **Reasons for updating a dataset** into a different version will be stored in the metadata for transparency. Rich metadata model that supports the **community standard(s)**. Networks maintain the **metadata describing the contributors, the measurement systems and observations** through the IT systems present at the Thematic Centres. **QC information** is added to the time series data files as separate columns with estimates of the **different kinds of uncertainty per parameter** or as columns with flag information. TCs provide the relevant station and person (plus role) metadata. **Instrument information** will be integrated and merged with the ICOS ontology to complete the provenance information of the observational data sets. Specific set of **metadata attached to each DOI** that must be provided during the minting process. If the PI information for a station for a certain period is corrected, this will automatically be reflected in the attribution information on the landing pages of data products from that station in that period and the citation strings for the relevant data sets. This is the same as when a new version of a data object arrives, which will automatically refer the landing page of the old version to point the user to the updated version (and vice versa).
F3: Metadata clearly and explicitly includes the identifier of the data it describes	The DOI associated with an ICOS data object or collection can be [...] linked to its metadata. The metadata [...] is [...] **enriched with information on the PID**, the checksum and other Object Specification-dependent metadata.

PRINCIPLE	HOW ADDRESSED
F4: (Meta)data is registered or indexed in a searchable resource	**B2FIND** for searchable metadata pointing to the datasets. The main entry point for data discovery for humans is data.icos-cp.eu. Data copy is streamed to the EUDAT **B2SAFE** server at CSC in Finland. The ICOS data can be exposed through the EUDAT **B2SHARE** service. The whole metadata store is available through the **SparQL endpoint**, including the OWL definitions, so that the complete metadata and its relations can be read for machine-to-machine communication. Sharing the metadata on (global) discovery portals like **GEOSS**, **WMO WDCGG** and the coming **ENVRI Hub** and **EOSC portal**. Automated data flow where ICOS L2 releases and NRT data can flow automatically into the **Obspack** new releases. Metadata becomes findable and accessible through the global DOI system and can be found using the **DataCite Search** engine, for example, that is harvested by **Google Dataset Search** and other search engines like **OpenAIRE Explore**. OTC made the historical Level 2 datasets from ICOS stations available that have been taken up in **SOCAT**. In the new **FLUXNET** setup in the near future it is proposed that the ICOS Ecosystem Level 2 data files produced by the ETC will be stored and transmitted using their ICOS minted DOIs and downloads will be either redirected straight to the Carbon Portal without going through the FLUXNET login and/or will use the download information forwarding API developed for Obspack. ICOS Atmosphere data files are submitted to the **WMO GAW World Data Centre for GHGs** (WDCGG). Transfer of NRT data into the **WIGOS** system and update of Level 2 data in the **WDCGG** database.
A1: (Meta)data is retrievable by their identifier using a standardised communication protocol	
A1.1: The protocol is open, free and universally implementable	Open-source software only, no dependencies on proprietary code and protocols. All ingestion data transport uses standard **http(s)** put and get methods. The metadata database can be queried using an **open SparQL endpoint**. Data access is provided through the PID (or DOI) of the data objects. Resolving this PID through the **Handle or DataCite DOI system** normally leads to a landing page that contains a link to the data object(s). When users access an ICOS data object, this will always go through using the persistent identifier of the data object.
A1.2: The protocol allows for an authentication and authorisation where necessary	Download facilities **including user identification**, disclaimer and licensing system. **The user can choose to register** themself but can also download the data anonymously.
A2: Metadata should be accessible, even when the data is no longer available	
I1: (Meta)data uses a formal, accessible, shared and broadly applicable language for knowledge representation	Ontology-based metadata store in RDF. Metadata packet in JSON format. The metadata store is fully described by the underlying ontology, that again itself is defined in RDF through the **OWL** language. ICOS keeps its metadata following an **ontology-based RDF store**. Extend the data landing pages with (json-ld) **schema.org tags**, next to the already available JSON, HTML, XML and Turtle **content negotiable** machine readable metadata formats. This will make data discoverable in Google dataset search.

PRINCIPLE	HOW ADDRESSED
I2: (Meta)data use vocabularies that follow the FAIR principles	
I3: (Meta)data include qualified references to other (meta)data	The ICOS ontology will be **mapped to the community and worldwide standards** by mapping the equivalences.
R1: (Meta)data is richly described with a plurality of accurate and relevant attributes	
R1.1: (Meta)data is released with a clear and accessible data usage licence	Data access will require the acceptance of a disclaimer and **data usage licence**. ICOS data is licensed under Creative Commons Attribution 4.0 international licence (**CC BY 4.0**). The download is first redirected to the ICOS data licence acceptance page, where the user is fully informed of the CC4BY licence and its conditions and has to check the box for acceptance of the licence before the download will start. For machine-to-machine data transfer, several **mechanisms exist to flag the acceptance of the data licence** to make the data transfer go ahead without interruptions.
R1.2: (Meta)data is associated with detailed provenance	All **measurement methods** follow published common specifications and protocols. **Datasets have their own provenance metadata** that describe the raw data used, versions of the software and scripts, settings, and the results of the automatic quality control. During the production of IW data and following quality checks, important **provenance information is generated** that needs to become part of the provenance metadata of Level 2 data. Some minimal provenance metadata
R1.3: (Meta) data meet domain-relevant community standards	The data is **quality controlled** and processed at dedicated central Thematic Centres, one for each domain, using **open and published processing chains**. Stations **meet the same precision requirements** as the main ICOS stations. The ICOS AS is equipped with **standardised and approved instruments** associated into an 'integrated' measurement system, controlled by a computer and custom-made software. ICOS ES follows a **set of rigorously standardised protocols** developed for the field ecosystem measurements. The ecosystem network adheres to the monitoring principles of the Global Climate and Terrestrial Observing Systems. Strict standardisation of instrumentation and procedures, and consequently the same level of data quality. The measurements are standardised due to protocols mutually agreed on by TC and MSA. Inclusion of the ICOS Atmosphere data into the **Globalview Obspack product**. Data files that **follow the WMO GAW** (World Meteorological Organization, Global Atmosphere Watch) specification. Provision of data in **netCDF format** and most importantly to follow the **WMO WIGOS** (WMO Integrated Global Observation System) metadata standard WMDS. Exchange of WIGOS metadata in the WMDS XML standard.

APPENDIX 3 KPI Overview

Category evaluated:

1 Management

1.1 General management

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
General management in a distributed research infrastructure such as ICOS RI shall ensure the smooth functioning of the entire organisation. It includes also compliance to laws, availability of agreements and regulations, and implemented managerial processes.	Aim: a well-functioning, well administrated RI To ask: How well internal management functions to oversee, integrate and steer core activities?	Elements to look at: • Management processes are in place • Documentation is available • Processes are well executed	KPI 1: Implementation of basic processes and availability of the basic documents describing them.	Process descriptions are comprehensive and including responsibilities. Cooperation agreements are signed and enable smooth organisation of work. Participants value the execution of meetings high. Documentation of meetings and their results is comprehensive.

1.2 Operational management

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
Operations are the core of any research infrastructure. The performance of stations and central facilities (CFs) needs to be thoroughly monitored.1	Aim: smooth operation of the RI To ask: How well internal management functions to oversee, integrate and steer the performance of stations and central facilities?	Elements to look at: • Station network standardisation • Compliance • Data coverage • Innovation management	KPI 2: Availability of technical requirements for ICOS instrumentation	Percentage of atmosphere variables that are standardised for instrumentation. Percentage of ecosystem variables that are standardised for instrumentation. Percentage of ocean variables that are standardised for instrumentation.
			KPI 3: Availability of ICOS approved operation practices for variables	Percentage of atmosphere variables that have approved operation practices. Percentage of ecosystem variables that have approved operation practices. Percentage of ocean variables that have approved operation practices.
			KPI 4: Effective station labelling	Number of labelled stations over time
			KPI 5: Comprehensive temporal data coverage	Temporal coverage of processed and quality-controlled data (L2) Coverage of ecosystem life cycle
			KPI 6: Comprehensive spatial coverage of observations	Spatial extension: network is large enough to picture the GHG status in Europe. Density: Network is dense enough to provide detailed information Biomes, climate zones, and land use covered
			KPI 7: Implementation of new technologies	New instruments tested/implemented New methodologies tested/implemented New data procedures developed/implemented Number of upstream industry cooperation activities

1.3 Data Management

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The main product of ICOS is high-precision, long term, observational data that supports the development of our scientific knowledge of the carbon cycle. This helps to better understand the greenhouse gas budget of Europe and its surroundings and provides the basis for the right policies needed to mitigate the risks of climate change.	Objective of the data lifecycle is a clear, reliable, transparent, and efficient workflow leading to the timely delivery of the data at the right quality. The main questions to be asked are: How well are the data systems designed and documented to warrant the transparent and timely delivery at the desired quality? How far does the data system comply with the FAIR principles?	Elements to look at: • Data workflows are well defined and effective • Data are timely • Data are compliant with FAIR principles • All data and data-related services are available via the Carbon Portal as the single-access point/ centralised entry gateway	KPI 8: Definitions of data workflows	Completeness of data workflow descriptions
			KPI 9: Timeliness of data provision	Timeliness of NRT and L2 data (to be defined)
			KPI 10: Data compliance with FAIR principles	Number of FAIR principles that ICOS complies to
			KPI 11: Availability of all data and data-related support and services via Carbon Portal	All data and data-related support are available via the Carbon Portal as the single-access point/centralised entry gateway Number of services for users

Category evaluated:

2 Finances

2.1 Core funding

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The strategic goal of financial management in a distributed research infrastructure such as ICOS RI is to achieve overall transparency and fiscal discipline. Furthermore, the analysis of the mid-term financial situation provides measures to mitigate financial risks. The mid-term financial situation is a plan and estimation of the next five years of funding.	The objective of the financial management is smooth resource allocation for the operations of the RI resulting in allocation of resources to priority needs, and efficient and effective provision of the defined output and impact as base for long-term sustainability of the funding.	Elements to look at: • Status of core funding	KPI 12: Amount, trend and volatility of core funding	Data on funding Perception of funding sufficiency
			KPI 13: Equity ratio	ICOS ERIC equity ratio CF?
			KPI 14: Mid-term financial sustainability	Mid-term financial sustainability of ERIC Mid-term financial sustainability of Central Facilities Mid-term financial sustainability of Station Networks Measures for monitoring financial sustainability exist Mitigation methods to prevent financial risks are monitored and applied as necessary

2.2 Project funding

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The ability to secure project funding as well as its internal distribution provides important information about the significance of the RI, its position within the research landscape and the internal integration.	Objective of the project funding is the availability of resource funding and its impact on the further development of ICOS.	Elements to look at: • Status of project funding	KPI 15: Amount, trend and volatility of external funding.	Data on funding (including success rate) Perception on internal integration of and participation in research projects as well as their impact.

Category evaluated:

3 Internal engagement and integration

3.1 Internal engagement

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
ICOS RI is essentially a mosaic of communities that take different geographical and focus-driven forms and operates on several scientifically differing domains. Due to ICOS RI consisting of several types of organisations, institutes of different agendas and histories and different cultural, political and linguistic areas, the perceived purpose of ICOS RI, the motivation to be part of ICOS RI, and the expectations from it vary among its members. This also means that the willingness and ability to engage with the RI activities and integrate with all of its components vary. It's important to know and to enhance motivation, identity and engagement as well as structures that support or hinder them. In the context of the evaluation and this report, 'engagement' refers to a range of behaviours: willingness to and interest in participating in activities – the signs of motivation.	Aim: An engaged RI To ask: How engaged and motivated ICOS RI is internally?	Elements to look at: • People identify with the RI • People are motivated	KPI 16: RI members identifying with ICOS	Felt level of recognition Identification with Behaviours
			KPI 17: Motivation of people involved in the ICOS RI operations	Participation Interest

3.2 Internal integration and structure

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
'Integration', on the other hand, refers to the RI's ability to include different parts of the RI into activities (meetings, events, documents, consultations, trainings, projects), the ability to improve activities and respond in an agile way to new opportunities or challenges and the potential for improving the RI's structure.	Aim: Integrated RI To ask: How integrated the RI is internally?	Elements to look at: • The organisational structure of ICOS RI is inclusive • The organisational structure of ICOS RI enables the improvement of activities • The organisational structure of ICOS RI functions well in managing the RI	KPI 18: The inclusiveness of the organisational structure of ICOS RI	Existing ways of including all parts of the RI, felt level of inclusiveness
			KPI 19: The ability of the organisational structure of ICOS RI to improve activities	Identified ways of possible improvements; felt level of the ability to improve activities
			KPI 20: The suitability of ICOS RI's organisational structure to manage the RI	Felt quality of the organisational structure, felt need to alter the structure

Category evaluated:

4 ICOS data and user expectations

4.1 A priori design

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The design of the observational networks should reflect user needs and international standards, to ensure that the provided datasets optimally support global and regional analysis of greenhouse gases.	Aim: A well-designed observational network that reflects user needs and international standards To ask: How well is the network designed and how well does it reflect the user needs and international standards?	Elements to look at: • ICOS participates or enables participation in international efforts to co-design standards for ICOS measurements.	KPI 21: ICOS-related participation in international efforts to co-design standards for ICOS measurements	Number of ECVs covered by ICOS observations. Number of international cooperation activities to standardise observations. Number of international cooperation activities to standardise observations.

4.2 Data download

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
Amount of ICOS data downloaded via Carbon Portal or other routes is a key success parameter for the attractiveness of ICOS.	Aim: ICOS data is downloaded and cited extensively To ask: How extensively is ICOS data downloaded and cited?	Elements to look at: • ICOS data is downloaded from the Carbon Portal by users in all ICOS domains. • ICOS data is downloaded via other portals (e.g., FLUXNET, SOCAT, ObsPack…)	KPI 22: Total amount of ICOS data downloads	Total amount of atmosphere data downloads from Carbon Portal: per year, per month, per parameter Total amount of ecosystem data downloads from Carbon Portal: per year, per month, per parameter Total amount of ocean data downloads from Carbon Portal: per year, per month, per parameter Total amount of atmosphere data downloads from other sources: per year, per month, per parameter Total amount of ecosystem data downloads from other sources: per year, per month, per parameter Total amount of ocean data downloads from other sources: per year, per month, per parameter Percentage of ICOS data cited Total amount of other data downloads from Carbon Portal: per year, per month, per parameter

4.3 Data usage

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
Use of ICOS data in the analysis of greenhouse gases in different scientific fields is a key success parameter for the value of ICOS data for the scientific community and the entire society.	Aim: Extensive usage of ICOS data To ask: How extensively is ICOS data used and does the usage reflect its the scientific value?	Elements to look at: • ICOS data is used and cited in scientific publications • ICOS data is used across different scientific fields • ICOS data is used in education	KPI 23: Research areas where ICOS data are used	Number of research areas according to Clarivate Web of Science
			KPI 24: Usage of ICOS data in publications and number of citations of publications using ICOS data	Number of publications per year Cumulative number of citations
			KPI 25: Application of ICOS data in (globally leading) models	Number and type of models that use ICOS data for calibration or validation
			KPI 26: Use of ICOS data towards support of satellite observations	Direct validation of satellite retrievals Validation of satellite-derived products
			KPI 27: Usage of ICOS data in educational tools and activities	Number of educational tools developed by ICOS (e.g., Jupyter notebooks) Number of education events using ICOS data

4.4 Active data promotion and meeting user/stakeholder expectations

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The mission of ICOS, as described in the ICOS Statutes, is to facilitate research by providing data but also through other related means. Additionally, the mission is to contribute with timely information relevant to the greenhouse gas policy and decision-making (Article 2 of ICOS Statutes). ICOS does not only passively wait for scientists to find its data, instead it is raising awareness of the data and services it provides for researchers and other users.	Aim: Actively promoted data and met user/ stakeholder expectations To ask: How well is data promoted and the user/ expectations met?	Elements to look at: • ICOS facilitates successfully scientific initiatives • ICOS Science Conferences successfully enable scientific exchange • Articles are published in online media/general media outlets and the RI is present in social media	KPI 28: Facilitation of scientific initiatives	Number of articles out of the ICOS-lead initiatives. Number of authors in the articles out of ICOS-lead initiatives
			KPI 29: Enabling scientific exchange through ICOS Science Conferences	Number of Abstracts submitted to the Science conference. Number of participants in the Science conference
			KPI 30: Engagement with social- and general media	Number of online media articles in general media outlets: Annual number of articles. Social media presence: Number of Twitter followers

4.5 Downstream private sector cooperation for ICOS data usage

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
The value of ICOS data and knowledge based on ICOS data increases when taken up by the private sector that develops services and solutions on climate change mitigation and adaptation.	Aim: ICOS RI cooperates with private sector/ ICOS data is used by the private sector To ask: how extensively is ICOS data used by the private sector?	Elements to look at: • ICOS wengages with downstream projects with private sector	KPI 31: Engagement in downstream projects with private sector	Share of data users from private sector. Number of projects with private sector. Publications with private sector

Category evaluated: 5 International cooperation

Integration of ICOS in European and Global GHG information systems

RATIONALE	OBJECTIVE	CRITERIA	KPIs	SUB-INDICATORS
Being a regional research infrastructure in Europe, ICOS needs to integrate itself into a global system of greenhouse gas observation since greenhouse gases don't stop at national borders. Data and information derived from global observations are thus a common societal objective, to address "the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge" (Paris Agreement).	Aim: ICOS is well integrated in European and global GHG information systems To ask: How well is ICOS integrated in European and global GHG information systems?	Elements to look at: • ICOS cooperates with the main actors of the European & global GHG information systems • ICOS is relevant in the global response to climate change • ICOS participates in events of regional or global relevance • ICOS has common observational sites with other RIs at country level • ICOS forms formal agreements (MoUs) with other RIs or organizations	KPI 32: Cooperation with the main actors of the European & global GHG information systems	Number and intensity of cooperation projects
			KPI 33: ICOS' relevance in the global response to climate change	
			KPI 34: Participation in events of regional or global relevance	Number of events participated per year
			KPI 35: Synergies and co-locations with other RIs	Number of common observational sites with other RIs at country level
			KPI 36: Formal agreements (MoUs) with other RIs or organizations	Number of formal agreements (MoUs) with other RIs or organizations

PHOTOS

Front page: Saclay Atmosphere station, FR

p. 5: Svartberget Atmosphere-Ecosystem station, SE

p. 12: Fontainebleau-Barbeau Ecosystem station, FR

p. 17: Svartberget Atmosphere-Ecosystem station, SE

p. 18: Grignon Ecosystem station, FR

p. 21: Simon Stevin and VLIZ Thornton Buoy Ocean stations, BE

p. 28: Zackenberg Fen Ecosystem station, Greenland, DK

p. 32 Loobos Ecosystem station, NL

p. 35: CanOA Ocean station, ES (photographer Melchor González Dávila)

p. 39: Jungfraujoch Atmosphere station, CH

p. 40: Lanžhot Ecosystem station, CZ

p. 46-47: Loobos Ecosystem station, NL

p. 49: Auchencorth Moss Ecosystem station, UK

p. 50: Simon Stevin Ocean station, BE

p. 53: Auchencorth Moss Ecosystem station, UK

p. 56, 57-58: Zeppelin Observatory Atmosphere station, Svalbard, NO

p. 60: Svartberget Atmosphere-Ecosystem station, SE

p. 62: Grignon Ecosystem station, FR

p. 66: Zackenberg Fen Ecosystem station, Greenland, DK

p. 73: Lanžhot Ecosystem station, CZ

p. 74: Auchencorth Moss Ecosystem station, UK

p. 79: Zackenberg Fen Ecosystem station, Greenland, DK

p. 81: Castelporziano 2 Ecosystem station, IT

p. 82: Zackenberg Fen Ecosystem station, Greenland, DK

p. 87: Pallas Sammaltunturi Atmosphere station, FI

p. 91: Loobos Ecosystem station, NL

p. 94-95: Castelporziano 2 Ecosystem station, IT

p. 96: Jungfraujoch Atmosphere station, CH

p. 104: Zackenberg Fen Ecosystem station, DK

p. 105: Zeppelin Observatory Atmosphere station, Svalbard, NO

Back cover: Fontainebleau-Barbeau Ecosystem station, FR

CONTACTS

ICOS ERIC Head Office
Erik Palménin aukio 1
FI-00560 Helsinki
Finland
info@icos-ri.eu

ICOS Carbon Portal
Lund University, Geocentrum II
Sölvegatan 12
22362 Lund
Sweden
info@icos-cp.eu

Atmosphere Thematic Centre (ATC)
Leonard Rivier
LSCE-Orme, point courrier 129, CEA-Orme des Merisiers
F-91191 Gif-sur-Yvette, CEDEX
France
contact-atc@lists.icos-ri.eu

Ecosystem Thematic Centre (ETC)
Dario Papale
DIBAF University of Tuscia, Largo dell'Università – Blocco D
01100 – Viterbo
Italy
contact-etc@lists.icos-ri.eu

Ocean Thematic Centre (OTC)
Richard Sanders
Nygårdsgaten 112
5008 Bergen
Norway
contact-otc@lists.icos-ri.eu

CENTRAL ANALYTICAL LABORATORIES (CAL)

ICOS - Flask and Calibration Laboratory (FCL)
Armin Jordan
Technologie Center am Felsenkeller (TCF) – Eingang C Kahlaische Str. 4
07745 Jena
Germany
contact-fcl@lists.icos-ri.eu

ICOS – Central Radiocarbon Laboratory (CRL), Karl Otto Münnich 14C Laboratory
Samuel Hammer
Heidelberg University
Institute of Environmental Physics
Berliner Straße 53
69120 Heidelberg
Germany
contact-crl@lists.icos-ri.eu

www icos-ri.eu

twitter.com/icos_ri

instagram.com/icosri

youtube.com/c/ICOSRI

linkedin.com/company/integrated-carbon-observation-system

ICOS | Integrated Carbon Observation System

ICOS (Integrated Carbon Observation System) is a European research infrastructure producing standardised high-quality greenhouse gas data in our 13 countries. Our data is free, and open for all users.

ICOS has been reviewed by an Evaluation Committee at the end of its five-year implementation period as per ICOS ERIC Statutes request. A set of key performance indicators (KPIs) were also established and evaluated. The evaluation was organised around five areas: management; financial management; internal engagement and integration; data and user expectations; and international cooperation.

The ICOS Five-Year Evaluation 2020 report presents the findings of the Evaluation Committee and should be read as a document that is complementary to the 'Evidence Report' compiled by ICOS ERIC.

www.icos-ri.eu
ISBN 978-952-69501-3-6