FIVE-YEAR EVALUATION OF ICOS: THE EVIDENCE

ICOS Integrated Carbon Observation System

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1 Introduction

1.1 ICOS

The Integrated Carbon Observation System (ICOS) is a distributed pan-European research infrastructure producing high-quality data of greenhouse gas concentrations in the atmosphere, as well as carbon fluxes between the atmosphere, the land surface and the oceans. It was listed on the first Roadmap for European Research Infrastructures in 2006, reaching its final legal status (ICOS ERIC) in 2015. The research infrastructure became fully operational towards the end of the first five-year period of ICOS ERIC (2015 – 2019), and this milestone seems to be the right time to evaluate the achievements so far.

ICOS' operations are based on observations provided by more than 140 standardised stations across Europe. These ICOS Stations are coordinated nationally by the ICOS National Networks from 11 Member countries and one Observer country. The number of stations varies greatly between countries. The age of the stations also varies, as some of them have been working for decades while others are new. All existing stations have been substantially re-equipped to comply with ICOS standards.

Compliance to ICOS standards is certified for all ICOS stations at the end of a two-step station labelling process performed by the Thematic Centres. Step 1 includes the overall evaluation of site, tower location etc. and Step 2 includes a thorough analysis of compliance with ICOS standards, measurement setup, data transfer and quality.

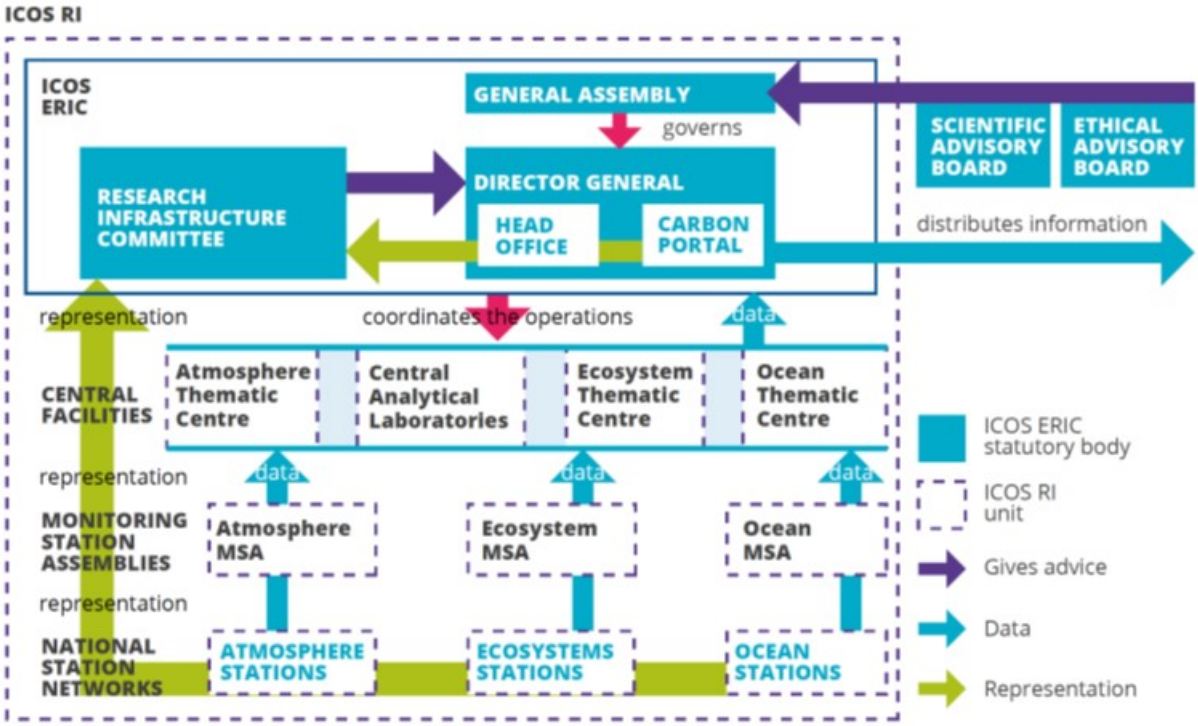


Figure 1: Structure and Governance of the ICOS research infrastructure.

The ICOS Research Infrastructure is coordinated by the Integrated Carbon Observation System European Research Infrastructure Consortium (ICOS ERIC) established on 23 November 2015 by nine European member states based on a regulation of the Council of the European Union (EC/723/2009) and a decision of the European Commission (Official Journal of the European Union 2015: L303/195). The Finnish Parliament has provided a Finnish law about legal personality and partial tax-exempt status in Finland according to which ICOS ERIC is a legal entity with legal capacity in Finland. ICOS ERIC has its registered Head Office in Helsinki. The number of participating countries at the time of writing is 12 (11 members and 1 observer). Spain has submitted its accession letter in October 2020. ICOS aims to

enlarge its observational capacity by attracting more member countries. ICOS ERIC does not include the entire perimeter of the research infrastructure instead coordinates the National Networks and Central Facilities via cooperation agreements.

The stations in the National Networks operate in three distinct domains: Atmosphere, Ecosystem and Ocean. Each domain has its own Monitoring Station Assembly (MSA) in which the Principal Investigators of the stations are represented to discuss, develop and improve the scientific and technical bases of the observations. The MSAs monitor, develop and improve the scientific and technical abilities of the station networks, working closely with ICOS Central Facilities, which include the Thematic Centres and Central Analytical Laboratories. The MSAs are represented in the ICOS RI Committee by the Chair and Vice-Chair to communicate and discuss the views and recommendations of the stations' operators.

Within each domain (Atmosphere, Ecosystem, Ocean), a Thematic Centre (called ATC, ETC and OTC respectively) coordinates the observations and supports the stations. In addition to the Thematic Centres, there are Central Analytical Laboratories (CALs) that provide gas analyses and calibration gases that follow the specifications by the World Meteorological Organisation. The Central Facilities coordinate and lead operations within their fields, process the data coming from the stations and run data quality checks. They play key roles in specialised analyses, metrology and technology watch, and support the measurement stations by offering spare instruments, training and technical assistance. The Central Facilities also have frequent interactions with one another for coordination, sensor interoperability and the standardisation of data archiving, data formats and processing methods. The Central Facilities are hosted by universities or research institutions in the Member countries.

ICOS ERIC consists of the Head Office, coordinating the RI operations, and the Carbon Portal, collecting and distributing ICOS data and derived products. In addition to coordinating, the Head Office is responsible for administration, management and development of the RI as well as for communication. The Carbon Portal in turn acts as the platform for the observational data and elaborated data products of the ICOS RI. It is a 'one-stop-shop' for all ICOS data products, a place where ICOS data, along with ancillary data, can be openly accessed.

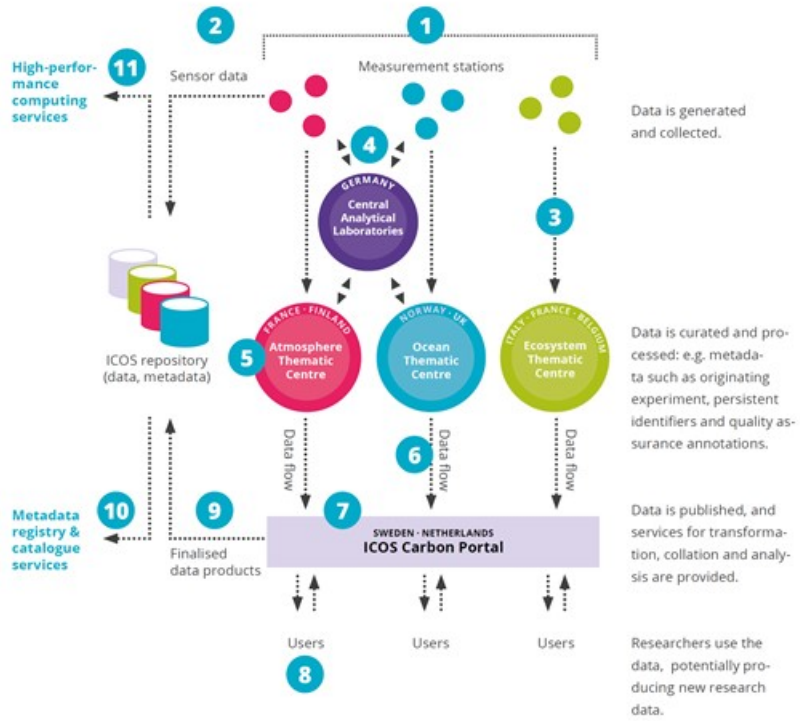


Figure 2: The ICOS data life cycle.

1.2 Purpose of the Evaluation

As one of the first larger distributed environmental Research Infrastructure and ESFRI Landmark, the Integrated Carbon Observation System (ICOS) has completed its implementation phase. At this point of its life cycle, it is important to evaluate the achievements, envisage the future operational phase, to justify and optimise the investments so far and support future financial support for the maintenance and continued development of the Research Infrastructure. The following words from the ESFRI Report on 'Long-term Sustainability of Research Infrastructures' describe the purpose of evaluating Research Infrastructures but also the challenge due to the lack of a standardised methodology:

> *'RIs are linked with needs of massive and long-term funding in the different phases – i.e., project-based funding in the design and preparatory phase, large investments in the implementation phase, steady and continuous funding in the operational phase, and costs associated with the last phase, which are usually not accounted for initially. Therefore, it is important that a standardized and effective evaluation methodology is established to justify the accountability of spending, to support evidence-based policy considerations and to make transparent funding decisions. Robust evaluation is also very useful to the RIs themselves, helping to maintain high standards, improve operational efficiency and inform strategy and planning. The user community also benefits because it informs them where the best services are offered, and where they need to be improved and inform their input into consultation with public authorities over their research strategy and planning. All of these organisations or bodies should play a role in setting up and conducting the evaluation. The evaluation should lead with the quality and the socio-economic impact of the science enabled by the RI as well as its technical excellence, but also include some or all of the following, depending on the point in the lifecycle of the RI: the strength of the services provided, including access policy, data management and exploitation, development of skills and outreach activity, the governance, management and operational efficiency.*
>
> *Evaluation should be conducted in an open, transparent manner by independent experts and as far as possible should use a common assessment framework across RIs or classes of RIs to enable evaluations performed in different countries to be as coherent as possible and to provide comparisons across different scientific domains. This, together with international members on review panels, will provide an international perspective to facilitate comparison with other national or international RIs, including exemplars, which is particularly important for those RIs distributed across different states. Evaluation must be also tailored to the characteristics of the Research Infrastructures, but still ensure that it covers specified objectives defined more generally for RIs, again facilitating strategic prioritisation for funding bodies.'* (Hrusak, Harrison, Lenoir, 2017)

Regular evaluations of ICOS are foreseen by the Statutes (Article 2) of ICOS ERIC in response to the ERIC Regulation (Article 10). This report describes the first larger evaluation of ICOS according to its statutes. The challenge of having no common assessment framework has resulted in an iterative process between the General Assembly, the Evaluation Committee, the different bodies of the Research Infrastructure and the Director General to develop an ICOS-specific but general evaluation framework that might also be a benchmark for other Research Infrastructures.

1.3 Description of the Procedure

The procedure towards the Evaluation comprised: (i) the development of the evaluation mandate and basic concept by the General Assembly of ICOS ERIC, (ii) the iterative concept development, (iii) the evidence material collection and (iv) the assessment of the collected information.

1.3.1 Evaluation Mandate Provided by the ICOS General Assembly

The General Assembly started to discuss and draft the evaluation mandate in November 2018.

Minutes of the 7th GA, 30.11.2018, Offenbach

> *General Assembly discussed the evaluation of ICOS ERIC and ICOS RI and decided the following:*

- *Evaluation timeline: beginning of 2020 until November 2020*
- *The Evaluation Committee will have five members including scientists and managers*
- *The General Assembly asks ICOS to:*
    - *to make study of the users and a study on the KPIs*
- *The evaluation will be made by external people*
- *The SAB will be included in the evaluation*

During this meeting, the Evaluation Preparation Committee (EPrepC) was founded and met twice during spring 2019. They elaborated the so called first evaluation mandate document (ICOS_GA08_2019_7_Evaluation mandate_draft.pdf). for the 8th GA in May 2019. This document states:

'The topic was discussed in the 7th General Assembly meeting, 30 November Offenbach, Germany.

The General Assembly closed session elected Jon Børre Ørbæk (Norway), Valerie Moulin (France) and Ritva Dammert (Finland) to an evaluation "preparation" committee.'

The document then confirms the decision of the 7th General Assembly (above) and continues:

'The Evaluation Preparation Committee held two Webex meetings 6 March and 16 April 2019. Meetings were attended by the Evaluation Preparation Committee, Chair of the General Assembly, Director General and Secretary of the General Assembly. In these meetings the evaluation process and preparation were discussed.'

The document was discussed at the 8th General Assembly. The minutes of the 8th General Assembly:

'7. For information: Draft Evaluation mandate

Norway's representative, Jon Børre Ørbæk presented the Draft Evaluation Mandate. He invited members to comment if there is something missing in the proposed evaluation criteria. An Evaluation Committee will be selected by General Assembly. An External Secretariat to assist the Evaluation Committee will be selected via a Call for Tender. The External Secretariat should organise the evaluation together with the Head Office and help in delivering the final report. The final mandate will be presented for approval and composition of the Committee agreed in the next regular General Assembly meeting.

Chair suggested for each country to propose no more than two people; one scientist and one administrative Nominee. Members should check with their nominee first whether they'd be willing to serve in the committee.

General Assembly decided that the compensation for the Evaluation Committee members is 2000€ per person for 3-5days of work.

Actions:

General Assembly to send their evaluation committee nominations by 15th September 2019 to inka.hella@icos-ri.eu with a short biography and justification.

General Assembly to send comments concerning the Evaluation Mandate to the Head Office which will forward them to the Evaluation Preparation Committee.'

The second evaluation-related document (ICOS_GA10_2019_8a_Draft outline of the Evaluation Concept.pdf) was presented to the 10th General Assembly meeting November 2019.

The minutes of the 10th General Assembly:

'8a. For approval: Draft outline of the evaluation concept of ICOS RI

Director General presented the draft outline of the evaluation concept of ICOS RI. General Assembly discussed the draft outline of the evaluation concept. It was proposed for the document to be discussed first with the RI and then with the Evaluation Committee as it is very important that the evaluation fits with the ideas of the community.

It was suggested to add a bullet point on the internal management aspect on the organisation of ICOS RI Com and RI, how HO is organised and function together with the CFs and so on. It was remarked that the committee should also analyse the potential to support knowledge and national decision making.

Chair remarked that the document is a very good start and that there should be an iteration process with the RI and a final approval by the General Assembly.

Director General remarked that the Evaluation Committee is due to start its work in January. Finalising the concept would be the first task and this would then be sent to General Assembly for approval electronically.

Director General remarked that the Head Office requires guidance regarding the secretariat for the Evaluation Committee.

General Assembly approved the draft Evaluation Concept with the timeline presented. General Assembly requested the Chair of the committee to hire a single person as a secretary for the committee, not an external company as a secretariat. The person to be located close by to the Chair of the committee. The General Assembly mandated the Director General to conduct further negotiations and decide on the final arrangement up to costs of 50 000 €. Money will be transferred from ICOS ERIC to the host institute of the Chair of the committee for that purpose.'

The evaluation concept put forth by the General Assembly described five main criteria to review ICOS performance:

- Internal management that oversees, integrates, and steers all core activities;
- Present and future key performance indicators (KPI);
- Based on this, how well the different parts function together and as entities and how well ICOS functions as one distributed and well-integrated infrastructure;
- How well ICOS outputs (i.e., data and services) fulfil user expectations;
- How well ICOS integrates into European and global greenhouse gas information systems.

1.3.2 Further Conceptualisation of the Evaluation

As the evaluation process was being conceptualised, the Evaluation Board decided to slightly change the criteria suggested by the General Assembly, since the KPIs should be developed as tasks cutting through all topics and different financial aspects were distributed. The final list of evaluation criteria was:

1. Management, including General Management, Operational Activities and Data Life Cycle
2. Financial management
3. Internal engagement and integration
4. ICOS data and user expectations
5. Integration of ICOS in European and Global GHG information systems

Furthermore, the Evaluation Committee developed a process to further refine the five main evaluation criteria and their sub-categories during the initial phase of its work (Figure 3). Based on the material collected initially, the Evaluation Committee refined the evaluation criteria, requested additional material and defined surveys and interviews.

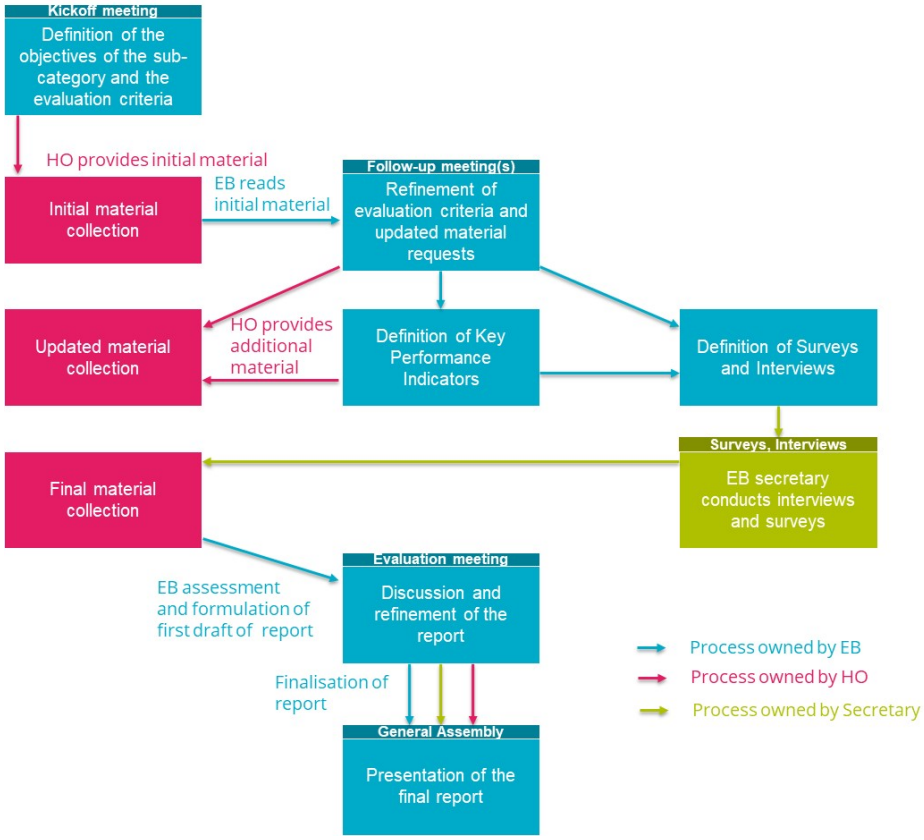


Figure 3: Process scheme of the Evaluation.

This part of the report comprises the final material collection for the Evaluation Board. Since it is based on the refinement of the evaluation criteria and the defined KPIs it also documents the process of conceptualisation.

This Evidence Report was compiled by the ICOS ERIC Head Office and acts as additional reading for the final Evaluation Report.

2 Key Performance Indicators (KPIs) Applied in the ICOS Evaluation

2.1 Performance and Impact

When measuring performance and impact, the common approach is derived either from the corporate world or from institutions and organisations with a long-standing societal position, e.g., NGOs (Non-Governmental Institutions). In those contexts, deriving measurable indicators and setting baselines to monitor and measure performance and impact have been developed and evaluated over a long period.

As RIs are a relatively recent organisational form, discussions about measuring their performance and impact have developed much more recently. Notwithstanding, as a result of the development of the RI landscape, the need to demonstrate their performance and subsequent impact has risen on many levels: For national and EU-level funding and strategy planning, and among RI operators who need to demonstrate their RIs' competence in the demanding landscape when competing for funding and recognition. This has led to the understanding that developing performance and impact indicators for RIs require approaches that are different from those commonly used in other fields.

For a systematic conceptualisation of the evaluation, it is important to note that ICOS comprises of strategic objectives, input-dependent activities and subsequent outputs. ICOS' purpose is defined by the needs and problems of the world it is embedded in and its performance manifests as outcomes and impact (see figure 4).

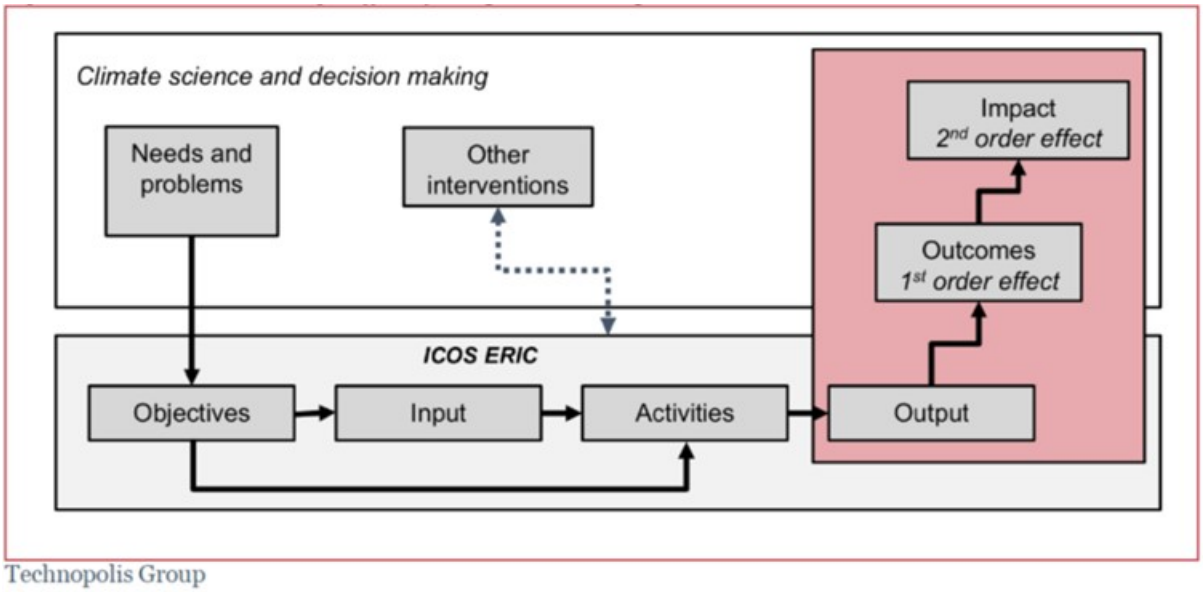


Figure 4: Basic frame of the ICOS Impact Assessment report to analyse effects from problem to impact.

ICOS' activities can be grouped under tasks, and the accomplished tasks will result in tangible deliverables (e.g., the outputs). Thus, the approach that ICOS RI is currently considering, is that most of the Key *Performance* Indicators are concrete and can often be related to outputs that demonstrate the RI's performance (e.g., operability and alignment with the goals in the statutes – in the case of an RI that is formed as an ERIC – and strategic goals compiled in a strategy document). The KPIs are directly linked to specific strategic core activities, each of which is formulated under specific strategic focus areas. The logic behind this structure is that when the RI performs compliantly (e.g., fulfils its set tasks and produces required deliverables i.e., output), it successfully executes its strategy and thus, fulfils its mission. The outcome of this performance can be seen as an effect – either a direct 'outcome' (1st order effect) or indirect 'impact' (2nd order effect). The effects can be shown by Key Impact Indicators.

Thus, both performance and impact are concepts that can be demonstrated on varying levels of detail and within time frames of different lengths (e.g., short-term performance and direct impact vs long-term performance and indirect impact). This imposes additional challenges in formulating their indicators. Additionally, to validate the performance and impact that have occurred, some baseline standards need to be set, against which the indicators can be analysed. The standards also need to establish whether e.g., performance means that a certain level of operation has been maintained, increased or decreased.

To further elaborate on this approach that recognises the two different groups of indicators, an extended two-level conceptual framework has been designed. In this framework, the RI's core activities are identified on an operative layer ('ICOS Activities'), consisting of a description of the structure that the RI utilises in executing its strategy with clear tasks and related deliverables (see figure 5).

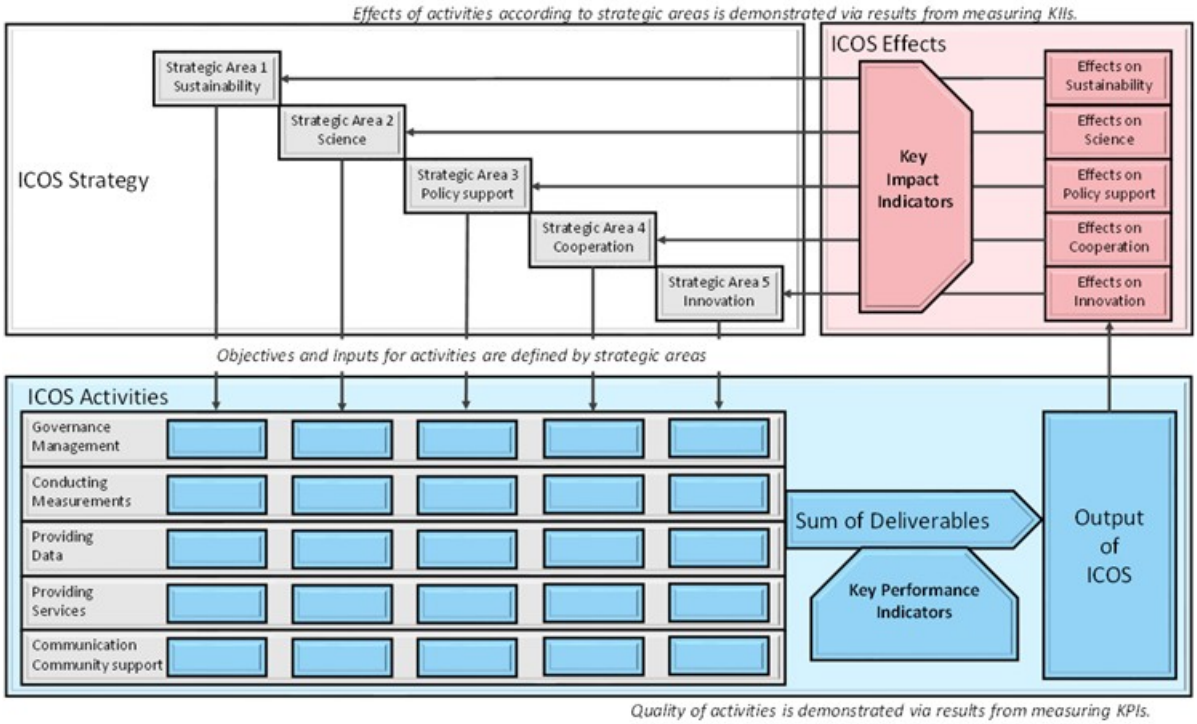


Figure 5: Two-level conceptual framework distinguishing between Key Performance Indicators and Key Impact Indicators. The five strategic areas and five key activities of ICOS form a matrix of 25 potential processes, each with deliverables that together define the output of ICOS (more detailed description in Chapter 2.3). Key performance indicators ideally measure the output of ICOS along these deliverables. The output has effects that can be related to the strategic areas and form in summary the impact of ICOS. Thus, the Key Impact Indicators should be related to the ICOS Strategy and provide a measure on how well the strategic goals of ICOS have been achieved.

Key Performance Indicators (KPIs) are used to demonstrate the materialisation of the core activities ('performance' by definition, includes an evaluation of how well an activity is done). The subsequent effect layer, which describes the areas where the RI aims to have an impact on society, is evaluated by the second set of indicators, the **Key Impact Indicators (KIIs)** that are used to demonstrate the materialised impact the RI's output is having or has had on society. The further grouping of Key Impact Indicators into direct (primary) and indirect (secondary) type effects as in figure 4 is left out for simplification.

There are three main advantages to this approach which keeps the RI agile in a fast-changing landscape:

- Both KPIs and KIIs are related to the strategy so can be related to each other.
- The two sets of indicators can be used to refine the strategy and consequently adjust the tasks.

- The integration between strategy, performance and impact is an elegant way to structure the overall management plan (Figure 5).

2.2 Sources and Concepts to Derive Key Performance Indicators

The key performance indicators derived for ICOS are based on three different sources:

The task 'Increasing the impact of ICOS' within the H2020 project RINGO

The approach described above was developed during the H2020 project 'Readiness of ICOS for Necessities of integrated Global Observations' (RINGO) responding to the call 'INFRADEV-03-2016-2017 - Individual support to ESFRI and other world-class research infrastructures'. RINGO was launched at the beginning of 2017. In anticipation of upcoming monitoring and evaluation efforts, it contained a task on increasing the impact of ICOS that has been extended step-wise to support the systematic process of developing framework that clearly distinguishes between performance and impact and allows a strategy-driven description of activities and related indicators. Furthermore, the report provided a systematic approach for the ICOS Management Plan. It has been delivered in December 2019.

The ESFRI working group report 'Monitoring of Research Infrastructures Performance'

In 2018 the European Strategic Forum on Research Infrastructures (ESFRI) established a Working Group (WG) to develop a common approach across Research Infrastructures (RIs) to monitor their performance based on Key Performance Indicators (KPIs). The proposed KPIs should provide a comprehensive framework ranging from input to outcome indicators. They will be used in the periodic review of ESFRI Landmarks and should be useful to be adopted by a wider range of RIs, funding authorities and stakeholders. The WG report was published in December 2019.

The ERIC regulation and the Statutes of ICOS ERIC

Article 2.2 (h) (referring to Article 10.g.ii of the ERIC regulation) and Article 20 of the ICOS statutes provide the coarse framework for the evaluation. The statutes foresee s*cientific and management evaluation of the activities, the strategic orientation and operation of all components of ICOS RI by external evaluators* (2.2h). *The panel shall give special attention to the fulfilment of user requirements* (Article 20).

For any further step, it is important to reconcile and integrate these three sources and the concepts behind.

2.3 Final Concept Applied in This Evaluation

During the conceptualisation of this evaluation, the KPIs were formulated along the evaluation categories defined in the mandate of the General Assembly and refined by the Evaluation Committee taking the other sources into account. The following conclusions were considered:

The most important common conclusion is that KPIs need to be closely connected to the objectives (ESFRI[1]) or strategic goals (RINGO[2]) respectively. This has been taken up in ICOS in a stepwise procedure:

[1] "*KPIs provide valuable information both for the operators of RIs and for their stakeholders to optimise progress towards the objectives through changes in inputs and activities*."
[2] "*The KPIs are directly linked to specific strategic core activities, each of which are formulated under specific strategic focus areas. The logic behind this structure assumes that when the RI performs compliantly (e.g. fulfils its set tasks and produces required deliverables; in other words, produces output), it successfully executes its strategy and in doing so, fulfils its mission*."

The first step focused on formulating a concise strategy (2017 – 2019), followed by then relating the core activities to strategic focus areas in the ICOS Management Plan (2019 – 2020) and finally providing indicators for the evaluation and long-term monitoring (2020).

Furthermore, KPIs should follow the RACER criteria, i.e., they should be:

- Relevant – i.e., closely linked to the objectives of the RI over a particular period of time.
- Accepted by the RIs (at all levels) and stakeholders otherwise there will be limited implementation.
- Credible for non-experts, unambiguous and easy to interpret.
- Easy to monitor – e.g., data collection should be possible at low cost.
- Robust – e.g., against manipulation.

Some of the KPIs should be derived annually and integrated into the annual report, while others should only be derived in five-year period and integrated in grand evaluations. In addition, there are some KPIs that are specific for the current position in the RI life cycle (Readiness Level 5 'Operation' according to the recent report by the European Commission 'Supporting the Transformative Impact of Research Infrastructures on European Research'). They will not be repeated in further evaluations.

An important aspect for future evaluation is that different evaluation aspects should be harmonised and integrated. The ICOS-internal evaluation and the annual reports should be used by ESFRI as well as by national evaluations in order to reduce the work load for the RI personnel.

2.4 KPIs Used in This Evaluation

Based on thorough reflections on the different sources, approaches and requirements the Evaluation Committee developed a set of 36 KPIs that was applied in this evaluation. Most of them can also be re-used in future evaluations to see the development of ICOS. Two types of KPIs were identified:

1) Quantitative indicators: These indicators provide well-defined numbers that also allow time-series with either annual values or re-calculation with a similar algorithm in a future evaluation. Examples for this type of indicators are temporal coverage of the station data, the number of data downloads, or the number of participants in the ICOS Science Conference.

2) Qualitative indicators: These indicators are important but provided by a narrative. The global cooperation towards standardised observations is a typical example of this type of indicators. Since the grand challenge of climate change is global, ICOS data can attain their full value only in standardised global data sets. The efforts to achieve this are an important part of the ICOS performance but not quantifiable.

2.5 Surveys as Additional Source of Information

In the framework of this evaluation, extensive surveys were sent to different internal and external target groups. They gave insights into the overarching view of the community but also viewpoints of specific groups such as the General Assembly, the Research Infrastructure Committee or the Station PIs. The results can be used as supportive indicators for the performance of ICOS as a whole or its specific bodies, such as the Head Office or Central Facilities. However, survey results do not have the same status of KPIs since they provide the subjective views of specific groups and results are heavily dependent on the survey being answered.

As an example, the very general statement: "ICOS RI is well managed" has been part of the surveys for all target groups. It received an average value of 3.75, on a scale from 1 (strongly disagree) to 5 (strongly agree) meaning that the overall management is seen as good but not excellent.

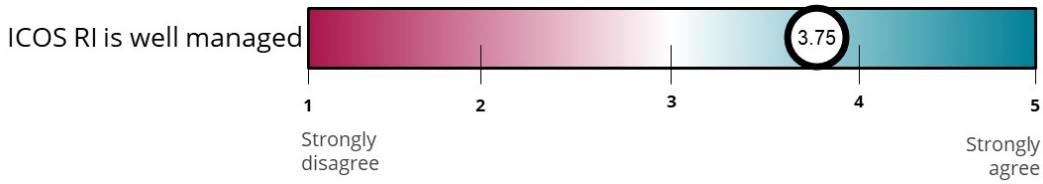


Figure 6: Example for the visualisation of the survey results.

Detailed questions underlying this very general question reveal different aspects of management (e.g., station labelling, data management, financial management) and separate entities (e.g., Head Office, Carbon Portal, Thematic Centres). Thus, the results show that some more general survey questions can support specific KPIs and can be asked again during the next evaluation, in 5 years, to document the development.

Survey questions: Category 1, Category 2, Category 3, Category 4, Category 5

Implementation of the surveys

The survey forms were created using Wufoo and distributed by email. Wufoo is an online survey tool, by SurveyMonkey, which makes it easy to distribute the surveys via email. While emailing the surveys, ICOS email lists or BCC-field were used to ensure information security. The surveys were sent on 4th September 2020, followed by two reminders on 11th and 16th September 2020.

Answer groups

Several groups answered the surveys. Some surveys were too long to fit into one Wufoo-form and thus were divided into two surveys (see table 1, CF coordinators and Station PIs). The subcategory names can be found in the table key. Most of the surveys had overlapping questions. The Scientific users and Stakeholders' surveys were separate and different from other surveys.

Table 1: Questions regarding different subcategories asked from different answer groups.

Survey ↓ **Subcategory →**	1.1	1.2	1.3	2.1	2.2	3.1	3.2	4	5
General Assembly	X		X	X			X		
RI COM members	X		X	X			X		
CF coordinators 1/2+2/2	1/2	1/2	1/2	1/2	2/2	2/2	2/2	2/2	
Station PIs 1/2+2/2	1/2	1/2	1/2	1/2	2/2	2/2	2/2	2/2	
Focal Points		X	X			X	X		
Heads of Units	X						X		
Scientific users								X	
Stakeholders									X
Director of Carbon Portal		X	X						

Key: 1.1 General management, 1.2 Operational management, 1.3 Data life cycle, 1.4 Financial management, 3.3 Resource related signs of integration, 3.1 Internal engagement, 3.2 Internal integration, 4 ICOS data and user expectations, 5 International cooperation

Answer rates

Groups that have a direct connection with ICOS, such as the Central facility coordinators, have a better answer rate than those more separate from ICOS (see table 2). The survey to the Stakeholders and Scientific data users had response rates of only 14% and 17%. However, the stakeholders that answered,

gave detailed and accurate answers. The survey to the Scientific users was designed to be relatively short and easy, to gain more entries.

Table 2: Final number of entries.

Group	Group size	Entries, number	Entries, per cent
CF coordinators 1/2 and 2/2	10+25 team members=35	28/25	80%/71%
Heads of Units	4	4	100%
ICOS Stakeholders	43+40 (BEERi) =83	12	14%
Station PI 1/2 and 2/2	110	50/48	45%/44%
Focal Points	13	11	85%
Director of Carbon Portal	1	1	100%
RI COM members	18	16	89%
General Assembly	27	13	48%
Scientific data users	200	33	17%

Key: CF=Central Facility, PI=Principal Investigator, RI COM=Research Infrastructure Committee, BEERi=Board of European environmental research infrastructures, provides direct advice to the ENVRI-FAIR project management

Central Facility coordinators and members -survey

In this survey, the Head Office (HO) and Carbon Portal (CP) were counted as central facilities. The survey was sent to the directors and heads of facilities, including all Heads of Units at ICOS ERIC. They were also asked, to forward the survey, to up to four team members each and inform the HO. To our knowledge, the survey was forwarded to:

- Operations unit (HO),
- Communications unit (HO),
- Administrations unit (HO),
- Carbon Portal,
- Ecosystem Thematic Centre,
- Atmospheric Thematic Centre,
- Ocean Thematic Centre and
- Central Radiocarbon Laboratory.

The people in this group had diverse backgrounds so were given the option to select 'not applicable' (N/A). E.g., the Head Office communications staff may not be familiar with data life cycle.

Multiple roles of some survey respondents

Some personnel had to fill in several surveys as they have different roles in boards and committees. E.g., all Heads of Units (HoUs) filled the HoU and the CF-coordinator survey, but some HoU are members of the Research Infrastructure Committee (RI COM) as well so answered the RI COM survey too. They were asked to consider their different roles while answering the questions. Between the two surveys, the RI COM survey is considered the primary one.

Category 1: Management

Since this is the first evaluation of ICOS at the end of the implementation phase, the managerial achievements should form a specific focus. ICOS RI has a complex distributed structure which needs an appropriate governance and management system. The evaluation should consider how ICOS manages its complexity.

1.1 General Management

Rationale

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.

Objective

General management's objective is a well-functioning, well administrated RI.

The main question to be asked is:

How well internal management functions to oversee, integrate and steer core activities?

Criteria 1 – 3

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

The elements to look at are the core management processes: Has ICOS RI thoroughly negotiated and implemented feasible internal rules and policies, a strategy, cooperation agreements about stations and facilities that are outside the ERIC? Are all crucial governance bodies well established and functioning? Are the management processes well documented and well executed?

KPIs

KPI 1: Implementation of basic processes and availability of the basic documents describing them.

This KPI is specific for the end of the implementation phase and will not be repeated in future evaluations. It is focusing on documents that regulate and describe basic management processes and supported by survey results regarding the quality of execution. Agreement to four very general statements were asked throughout the entire RI and thus can support the evaluation of the overall management. They are introduced in the respective chapter. The KPI is narrative and includes four parameters.

- Process descriptions are comprehensive and including responsibilities.
- Cooperation agreements are signed and enable smooth organisation of work.
- Participants value the execution of meetings.
- Documentation of meetings and their results is comprehensive.

Evidence

The governance structure of ICOS is describes in Chapter 1 (Figure 1). The managerial work during the first five years has resulted in a collection of internal rules and management documents and finally shaped an integrated management system for ICOS that allows for a clear description of the core activities of ICOS as defined by the statutes and the strategy, and define a hierarchical system of related processes and tasks. The rules and policies developed during the design and implementation phase are currently integrated into a comprehensive Management Plan (first draft presented to the General Assembly in November 2020).

Table 1.1: Evidence material for subcategory 1.1

Document	KPI
1. Setting up ICOS ERIC (2013 – 2015)	
ICOS ERIC statutes (Statutes)	1
Technical and scientific description for ERIC application (Technical and Scientific Description)	1
2. Setting up the internal legal framework and procedures (2014 – 2017)	
ICOS ERIC – Central Facilities cooperation agreements (ATC) (CRL) (ETC) (FCL) (OTC) (CP)	1
ICOS ERIC – National Networks cooperation agreement (Network agreement)	1
ICOS ERIC – JRC framework agreement (JRC)	1
Financial rules and routines (see Category 2) Operational management (see Chapter 1.2) and data life cycle (see Chapter 1.3)	1
3. Developing terms of reference and rules of procedures for internal governance (2015 – 2017)	
Terms of reference General Assembly (RoP)	1
Terms of reference Scientific Advisory Board (ICOS_SAB_ToR_2.0 APPROVED.pdf)	1
Terms of reference Ethical Advisory Board (EAB ToR)	1
Rule on conflict of interests (Conflict of Interest APPROVED.docx)	1
Rule on project participation (Guidelines for participation in the projects-approved by GA.pdf)	1
Rule on cooperation (Cooperation rules)	1
Statement on procurement policy (18 Statement about Procurement Policy.pdf)	1
ICOS ERIC employment policy (Employment policy)	1
ICOS ERIC staff rules (Staff rules)	1
Communication strategy (Communication strategy)	1
4. Refining mandate and strategy (2017 – 2019)	
ICOS Strategy (ICOS Strategy)	
5. Management plan (Compilation in 2020)	
ICOS Draft Management Plan (ICOS Draft Management Plan presented to 12th GA)	

ICOS has, furthermore, established a document management system where notes and minutes of the meetings are shared. RICOM and Heads of Units in the Head Office have a rolling list of actions, from where unresolved issues are taken to agenda of following meetings.

Survey questions regarding the general management were asked to General Assembly, RI COM, Focal Points, Central Facilities, Heads of Units and Station PIs. The complete list of survey questions related to Category 1 (General Management) can be found in this file.

Results of the surveys

Four very general statements were part of the surveys for all target groups. The first statement 'ICOS is well managed' received an average value of 3.75 in scale from 1 (strongly disagree) to 5 (strongly agree) meaning that the overall management is seen as good but not excellent. The second question gives impression that the management has improved during the past years.

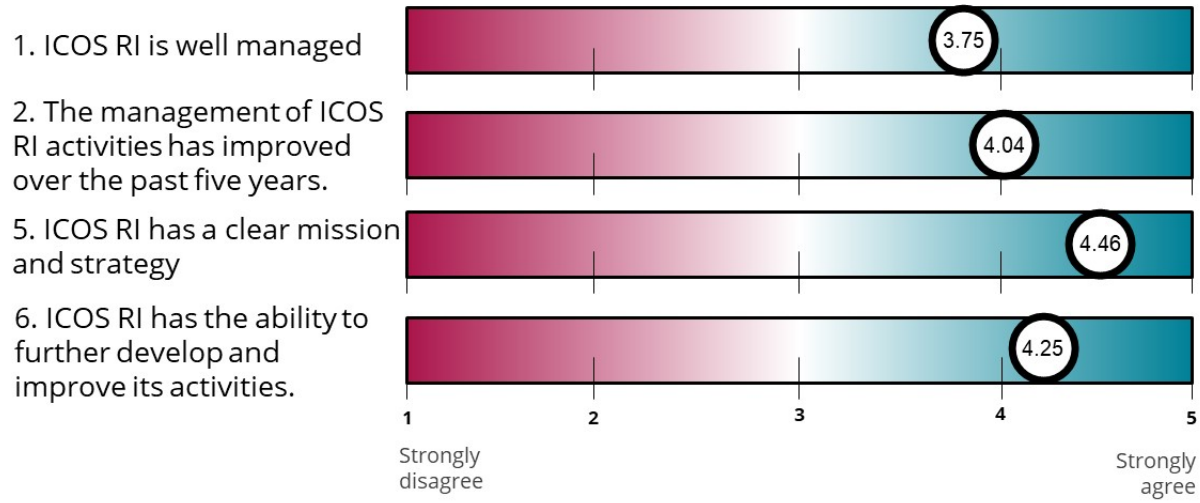


Figure 1.1: Indices on general management.

A very high agreement has been given to the statement that ICOS has a clear mission and strategy which is an important feedback to the long process on discussing and writing a strategy document during 2018 and 2019. The ability to further develop and improve the ICOS activities also received a high score.

The survey comprised many detailed questions on the management and execution of core meetings. Figure 1.2 shows averages on about 10 statements regarding the management of these assemblies given by the respective assembly members.

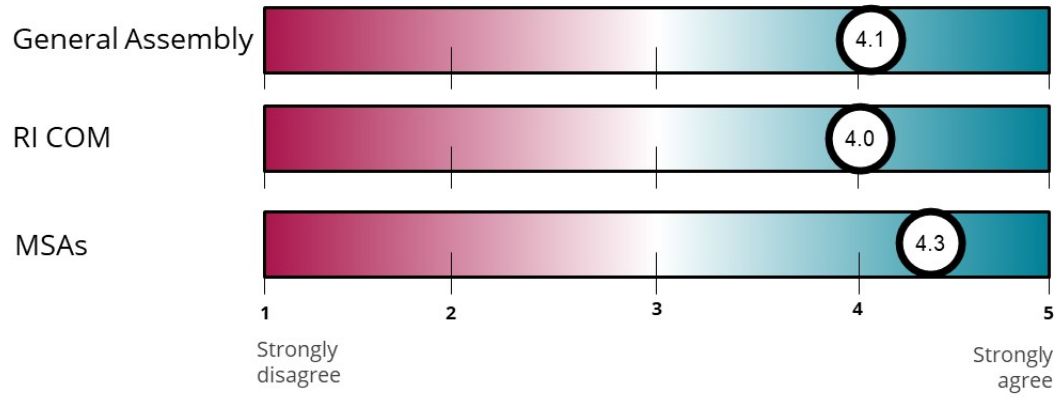


Figure 1.2: Integrated indices on management of GA, RI COM and MSA meetings.

Detailed information on the survey results is provided in the Appendix and will be used by the Head Office and the Director General to further optimise the general management.

Communication is another important aspect of general management. The statement "I am well informed about ICOS in-between the meetings" received an overall agreement of 4.0 with a slightly lower value by the Station PIs who attend the MSAs (3.78). The statement "The communication is efficient between the Head Office/Director General and my Central Facility" received an agreement of 3.9 among the CF personnel.

The survey included open answers which are briefly summarized here: Some answerers suggested that scientific user committee would improve the work of the RI, while others thought reducing and focusing activities would be better. Complicated, distributed structure and the resulting funding issues were seen as an obstacle for rapid adaptation. It was also stated that the performance would be improved if the DG would delegate more administration to HO staff and more outreach to CFs and scientists, and clarify responsibilities.

1.2 Operational Management

Rationale

Operations are the core of any research infrastructure. The performance of stations and central facilities (CFs) needs to be thoroughly monitored.

Objective

Objective of the operational management is smooth operation of the RI.

The main questions to be asked are:
How well internal management functions to oversee, integrate and steer the performance of stations and central facilities?

Criterion 1: Station network standardisation

How well does ICOS have the requirements for stations? This is aiming to define homogenous network in each domain. This comprises technical standards as well as operational practises.

KPI's for Criterion 1

KPI 2: Availability of technical requirements for ICOS instrumentation
The KPI monitors the degree of standardisation. It is numerical and measures the percentage of variables that are standardised for instrumentation. This is provided per domain.

KPI 3: Availability of ICOS approved operation practices for variables
The KPI monitors also the degree of standardisation. It is numerical and measures the percentage of variables that have descriptions of the operational procedure. This is provided per domain.

Criterion 2: Compliance

How well do the stations in each domain match the above-described standards? The process of compliance control and certification is called 'labelling' in ICOS and the performance of stations and Thematic Centres in this process is reflected.

KPI's for Criterion 2

KPI 4: Effective station labelling
The KPI is numeric and monitors the number of labelled stations over time in each domain and country.

Criterion 3: Data coverage

Does ICOS provide data at acceptable intervals in space and time to allow conclusions to be derived about the GHG situation in Europe?

KPI's for Criterion 3

KPI 5: Comprehensive temporal data coverage
The KPI is currently narrative giving examples but will be further developed in the future to a full coverage of raw (L0) data and processed and quality-controlled data (L2) in all domains.

KPI 6: Comprehensive spatial coverage of observations
The KPI is narrative and explores the spatial extension and the density in relation to the knowledge on the GHG in Europe

Criterion 4: Innovation management

How well does the RI adapt to advancements in technology?

KPI's for Criterion 4

KPI 7: Implementation of new technologies
The KPI is partly numerical and partly narrative, describes the number of new technologies, methodologies, and data procedures that are tested, implemented. It includes upstream cooperation with industry.

Evidence

Evidence for Criterion 1: Station network standardization

Table 1.2: Evidence material for subcategory 1.2, criterion 1

Documents available online	**KPI**
ICOS Handbook 2020	2, 3
Ecosystem protocols published 2018 in a special issue of International Agrophysics	2, 3
Instructions and guidelines for ICOS Ecosystem Stations	2, 3
Atmosphere station specification 2020	2, 3
ICOS Ocean station labelling, Step 2	2, 3
Guide to Best Practices for Ocean CO_2 Measurements (Dickson et al. 2007)	3

Documents in the Material folders	**KPI**
Standard Operational Procedures Overview (SOPs)	3

ICOS marine stations labelling track	2

Survey questions related to subcategory 1.2, criterion 1	Target group
26. The status of standardisation in ICOS/in my domain is good. 27. If you disagree, what would you improve?	Station PIs
22. The status of standardization in ICOS/in my domain is good. 23. What would you improve?	CF Coordinators

During the design and early implementation phase, the measurements conducted by ICOS were thoroughly standardised. The standardisation has been achieved in discussions in the Monitoring Station Assemblies, and documented by the Central Facilities.

In the **Atmosphere** component the standardisation is documented in the ICOS Atmosphere Station Specifications, a living document that is continuously updated by the ATC and the Atmosphere MSA. The document describes instrument requirements. The ATC metrology lab has tested continuous gas analysis instruments for compliance with ICOS requirements and provided a list of compliant instruments. Compliance of other instrumentation to ICOS requirements has been monitored according to manufacturers' descriptions. The station specifications provide detailed operational procedures on sensor installation, calibration etc. An overview is given in table 1.3.

Table 1.3: Overview of instrument requirements and operational procedures in the Atmosphere network of ICOS.

Variables	Instrument requirements	Operational procedures
Continuous analysis of gases	Requirements for range precision and repeatability available and tested instruments marked as ICOS-compliant.	Detailed description comprising e.g., sensor installation, tubing, calibration, room temperatures for instrumentation.
Gases, periodical sampling	ICOS has developed own standard instruments that are applied at the stations.	Standardised sampling and standardised and centralised lab analyses. In addition, a sampling strategy was developed to optimise information gain.
Meteorology, continuous	Requirements for range precision and repeatability available. List of instruments marked as ICOS-compliant.	Detailed description comprising e.g., sensor installation, tubing, calibration.

Extensive discussions within the **Ecosystem** community have yielded a coherent set of protocols for standardised observations at ICOS ecosystem stations. 13 protocols were published in 2018 in a special issue of International Agrophysics. The protocols represent a trade-off between an ideal approach and the practical feasibility of an ambitious measurement plan. They built on the experiences from previous monitoring and experimental research networks under careful consideration of the requirements from

multiple data user categories. Whereas the protocols explicitly explain the usefulness and scientific background of the observations and justify the choice of the methods, specific instruction documents provide guidance to the practical implementation of the protocols for the personnel working in the field. These protocols describe operational procedures for all the mandatory variables, and the ETC provides detailed instructions for 85% of all variables. Requirements about instrumentation are not necessary for all variables in the Ecosystem network (for example taking leaf samples). Instrumentation instructions are given for 87% of those variables where specific instruments are needed. An overview is given in table 1.4.

Table 1.4: Overview of instrument requirements and operational procedures in the Ecosystem network of ICOS.

Variables	Instrument requirements	Operational procedures
Fluxes of CO_2, H_2O, CH_4 and N_2O determined by eddy covariance measurements	Instruments are standardised.	Detailed descriptions for sensor installation, calibration, and maintenance. Data transmission and processing are also standardised and centralised.
Soil efflux of CO_2, CH_4 and N_2O determined by chamber measurements	Basic method requirements and requirements for analyser in the protocol.	Protocol describes chamber design of chambers and soil collars, routines to avoid influence of measurements on soil properties and optimum calculation of fluxes.
Meteorology, continuous	Requirements for range precision and repeatability available.	Detailed descriptions comprising e.g., sensor installation, calibration.
Periodical sampling of soil and foliage.	No instrumentation standards necessary.	Standardised sampling and standardised and centralised lab analyses.
Periodical sampling of vegetation properties (e.g., Green Area Index (GAI), litterfall or biomass)	No instrumentation standards necessary.	Standardised sampling and standardised and centralised data analyses (for GAI).

In the ocean component, the instrument requirements and the operational procedures of ICOS are mainly build on Guide to Best Practices for Ocean CO_2 Measurements (Dickson et al. 2007) which provides detailed standard operating procedures (SOPs), that have been subjected to open review by the ocean carbon science community and describe well-tested methods. Since they are intended to provide standard procedures together with an appropriate quality control plan, for the entire global network, ICOS OTC did not develop own instructions and procedures but updated and clarified some of the procedures. All instruments used have requirements for accuracy but no standard instrumentation is defined. The operational procedures are described in detail. For calibration, OTC allows either use of certified calibration facility or in-house methods, but these must be thoroughly documented.

Core results from the survey related to Criterion 1

Station PIs as well as Central Facilities have a very positive attitude towards the state of the standardisation in ICOS.

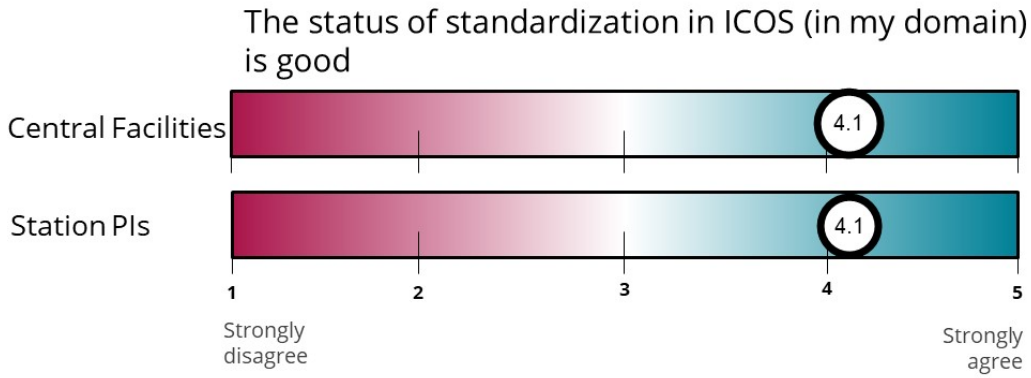


Figure 1.3: Survey results on the state of standardisation in ICOS.

CF coordinators and PIs were asked, what they would improve in the standardisation.

The CF coordinators suggested focus on implementing internationally recognised standards and to a core of essential variables (turbulent variables, micrometeorological variables, soil water) and to be more flexible for ancillary data. They also thought that a centralised calibration service would help, and could have more funding to hire personnel.

Station PIs suggested regular station audits, and scientific justification for selected methods (as opposed to experience-based selection). Two specific methods were mentioned as missing or suboptimal. They would also prefer less dependence on specific manufacturers.

Evidence for Criterion 2: Compliance

Table 1.5: Evidence material for subcategory 1.2, criterion 2

Documents available online	**KPI**
ICOS Handbook 2020	4
Labelling report executive summaries ETC ATC and OTC	4
Labelling status (interactive app)	4

Survey questions	**KPI**
1. The labelling process for the ICOS measurement stations in my country is completed. 2. If you disagree, what are the reasons? 3. The labelling process is efficient. 4. If you disagree, what are the bottlenecks?)	Focal points
28a. The station labelling process of my domain is Straightforward 28b. The station labelling process of my domain is Efficient 29. If you disagree, what are the bottlenecks?	Station PIs

30. I receive/received sufficient support from the Central Facilities during the labelling process. 31. If you did not receive sufficient support from the Central Facilities during the labelling process, what did you miss?	
24a. The station labelling process of my domain is Straightforward 24b. The station labelling process of my domain is Efficient 25. If you disagree, how would you improve it?	CF Coordinators

The compliance of a station to the standards is confirmed in a thorough station certification process (known in ICOS as "Labelling"). The labelling documentation goes beyond the Standard Operation Procedures. Labelling of a station is confirmed in three steps. The final Step 3 'acceptance' happens in meetings of General Assembly, typically twice a year. By the last GA meeting during this evaluation, in November 2020, 68 of the 146 stations have been labelled. 44% of these stations progressed from entering Step 2 to the Step 3 (final approval by GA) in less than a year. Reasons for the slow process may be related to low resources at station but also to efficiency of the process as organised by the Thematic Centres.

Table 1.6: Labelled stations per country, domain and station type (C1=Class 1, full set of measurements, C2=Class 2, basic set of measurements, Assoc=Associated station, a set of key measurements)

Status of the ICOS Station Labelling in November 2020 vs station numbers 2021

Member/ Observer countries	Stations total (2021)	Labelled station total	Number and type of stations. C1= Class1 (full measurements), C2=Class2 (basic measurements) Assoc= Associated station (a set of key measurements)														% labelled per country
			Ecosystem stations						Atmospheric stations				Ocean stations				
			C1	C1 labelled	C2	C2 labelled	Assoc.	Asso. labelled	C1	C1 labelled	C2	C2 labelled	C1	C1 labelled	C2	C2 labelled	
Belgium	11	7	1	1	4	3	2	1	0		1	1	2	1	1	0	64 %
Czech Rep.	4	1	1		1		1		1	1	0		0		0		25 %
Denmark	10	1	2	1	1	0	6	0	0		1	0	0		0		10 %
Finland	13	9	2	1	2	1	5	4	2	2	2	1	0		0		69 %
France	23	13	3	2	6	1	9	5	3	2	1	2	1	1	0		57 %
Germany	36	16	5	4	0		14	3	7	6	5	2	4	0	1	1	44 %
Italy	17	5	2	0	2	0	6	2	0		3	2	1	1	3		29 %
Netherlands	3	1	0		1		0		1		1	1	0		0		33 %
Norway	7	4	0		1		0		1	1	1	0	3	2	1	1	57 %
Spain	2	0	0		0		0		0		1	0	1	0	0		0 %
Sweden	11	7	0		6	4	0		3	3	0		2	0	0		64 %
Switzerland	2	2	1	1	0		0		1	1	0		0		0		100 %
UK	6	0	1	0	0		0		0		2	0	0		3	0	0 %
JRC	2	2	0		1	1	0		0		1	1	0		0		100 %
Total	147	68	18	10	25	10	43	15	19	16	19	10	14	5	9	2	46 %
				56 %		40 %		35 %		84 %		53 %		31 %		29 %	

Core results from the survey related to Criterion 2

Figure 1.4 shows the survey results regarding the efficiency of the labelling process. The Focal Points neither agreed nor disagreed to the statement, while station PIs are a bit more positive with highest values related by the Ocean station PIs (4.1) and lowest to the Ecosystem station PIs (3.2). The Central Facilities' agreement is the highest.

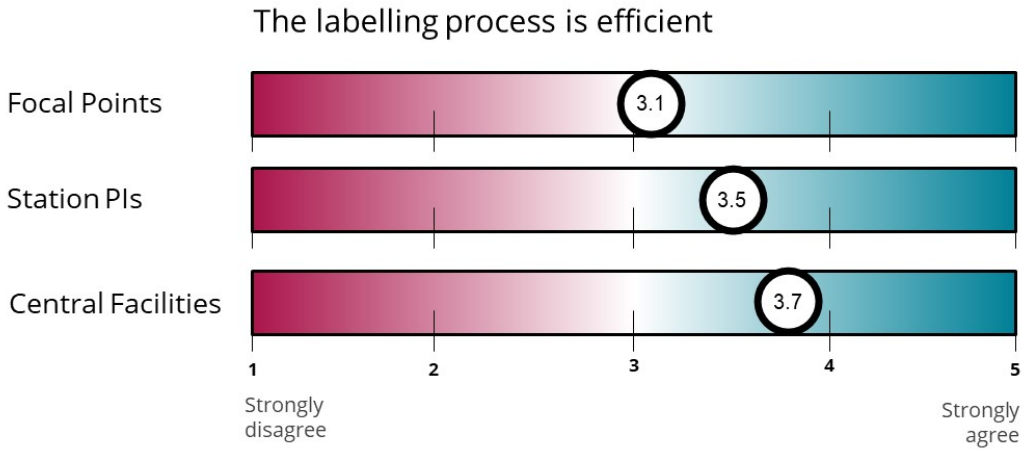


Figure 1.4: Survey results on the efficiency of the labelling process (the certification of the stations).

Several focal points and PIs mention as primary reason for delays in labelling being the resources available at stations, not in thematic centres. However, they see space for improvement in clarity of the instructions and simplification of the procedures.

Evidence for Criterion 3: Data coverage

Table 1.7: Evidence material for subcategory 1.2, criterion 3

Documents available online	**KPI**
ICOS Handbook 2020	5, 6

Survey Questions	**Target group**
5. The spatial coverage of ICOS data in my country is adequate. 6. Please, select up to 5 of the most important limitations for improving temporal data coverage from stations in your country. 7. Please, explain what kind of plans your country has to improve data coverage.	Focal points
32. I consider my station unique and important considering spatial coverage of ICOS data. 33. The temporal data coverage of my station is good. 34. Please, select up to 5 of the most important reasons for data losses at your station.	Station PIs
26. The data coverage in ICOS/in my domain is comprehensive. 27. How does or how could your Central Facility support improvement of the data coverage?	CF Coordinators

Spatial coverage has several aspects:

The overall area covered by ICOS atmosphere observations can be described by the combined footprints of all the atmosphere stations. All ICOS atmosphere stations cover 81.3% of land area of the member countries, currently labelled stations cover 75.7% (Figure 1.5).

Spatial coverage of ecosystem stations is shown as number per ecosystem probed (Table 1.8). It could be further improved by covering climate zones (e.g., Köppen-Geiger climate classification system or a simpler mean annual temperature vs mean annual precipitation matrix), representation of major biomes, or representation of land use and management. This is to be done in the future years.

Table 1.8: Ecosystem stations in relation to the station type and the type of ecosystem probed.

Station type	Class 1	Class 2	Associated	Total
Agricultural	3	5	5	13
Forest	9	13	17	39
Grassland	4	7	8	19
Peatland	1	1	2	4
Lake	0	0	1	1
Urban	0	0	1	1
Wetland	1	3	5	9
Total	18	29	39	86

For Ocean domain, the optimal status of the network is that there should be

i) Stations in all major European sea areas,
ii) Enough stations to understand and quantify uptake in European seas when their data is combined with other platforms,
iii) Enough stations to act as a reference network against which other platforms that require intensive calibration can be validated.

The simplest (although not the best) way that the progress towards these goals can be measured is to determine the faction of ICOS countries with an ocean presence that have a station. By this metric the network is 72% complete.

However, there are important European ocean nations that are not ICOS members (e.g., Portugal, Greece, Ireland, Iceland) and some countries do not have presence in all areas (e.g., where a country has coastlines in two seas such as the N Sea and NE Atlantic or the NE Atlantic and the Mediterranean) it would seem reasonable to make ICOS observations in both. Furthermore, there are areas beyond national jurisdiction that fall naturally to European states which require some observations – some of which are effectively covered now but others are not. Thus, we regard the 72% as an upper limit of the extent to which the network is complete, with the reality being that it is probably much lower.

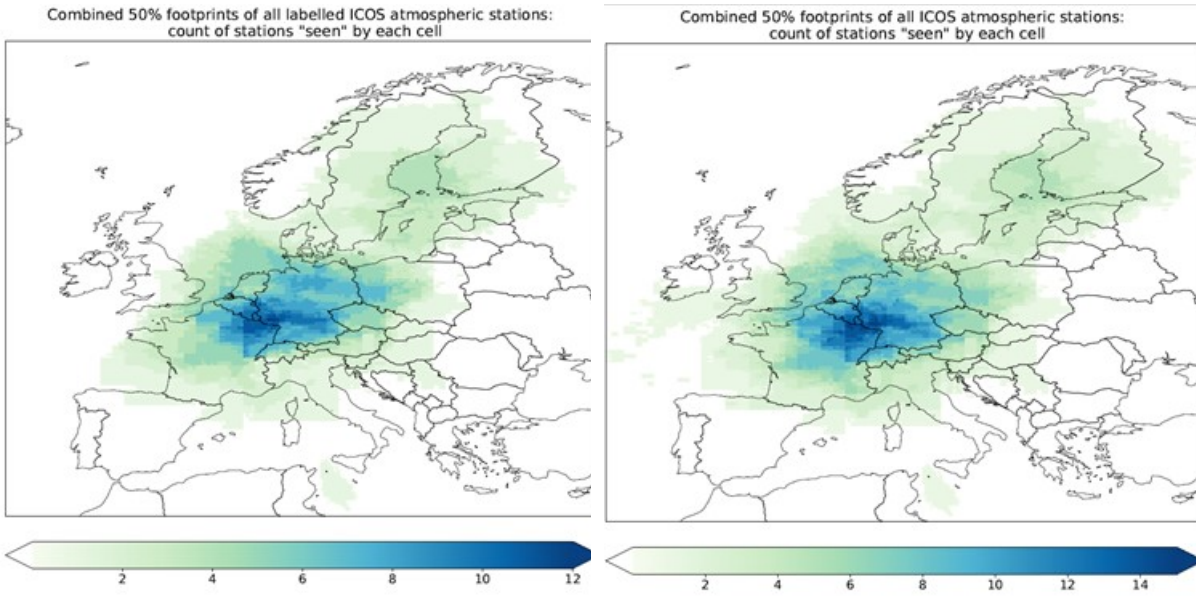


Figure 1.5: Combined footprints of all labelled (left) and all (right) Atmosphere stations. The colour illustrates how many stations cover a certain point. 55% of area of member countries is covered with footprint of at least one station. The footprint is defined as the area which is includes in the source area of the station at least 50% of time.

To illustrate the impact of the network coverage, the figure 1.6 shows that the uncertainty reduction in inverse models calculating continental GHG fluxes by atmosphere observations is mainly occurring within an array of atmosphere towers.

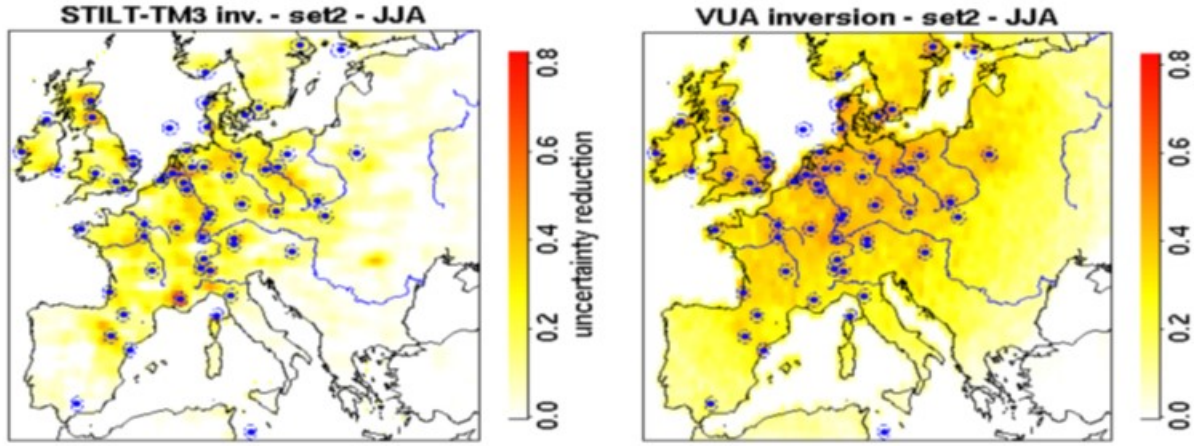


Figure 1.6: Uncertainty reduction in two inverse models based on a hypothetical ensemble of ICOS atmosphere stations.

The countries currently participating in ICOS represent about 43% of the land area of Europe (including the European part of the Russian Federation and Greenland). Increasing the coverage depends on the complex procedure of countries joining ICOS ERIC. For extension of the network, RINGO WP 2 was concentrating in helping new countries join ICOS, and Spain recently joined ICOS. Poland and Ireland are quite far in the process. (Inclusion of Poland and Ireland would increase the coverage to 46%).

Temporal coverage can be illustrated with heat maps, which illustrate per week and per station percentage of maximum data made available at the Carbon Portal (Figure 1.7).

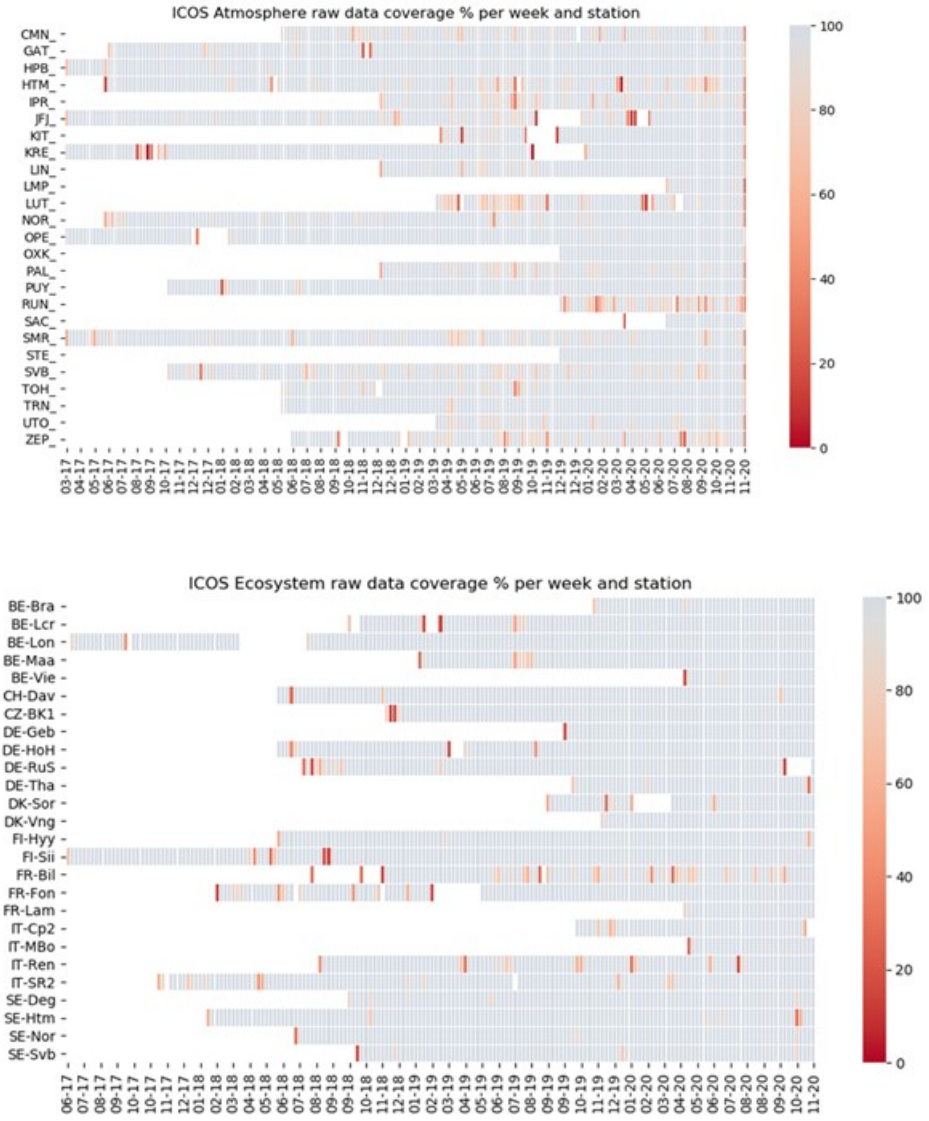


Figure 1.7: Temporal coverage (data availability) per week and per station at all labelled Atmosphere (upper panel) and Ecosystem (lower panel) stations. Only labelled stations (41% of ecosystem, 68% atmosphere stations) are shown here as they are the ones producing ICOS data to Carbon Portal. The 0-data periods in beginning are related to that individual station not yet being labelled. Average value is over 99%.

The PIs were asked to select up to 5 of the most important reasons for data losses at their station. Most common ones were failures of either the instrument (31 mentions) or infrastructure (power, air condition, technical gases, internet connection etc., 28 mentions). The distribution is shown in figure 1.8.

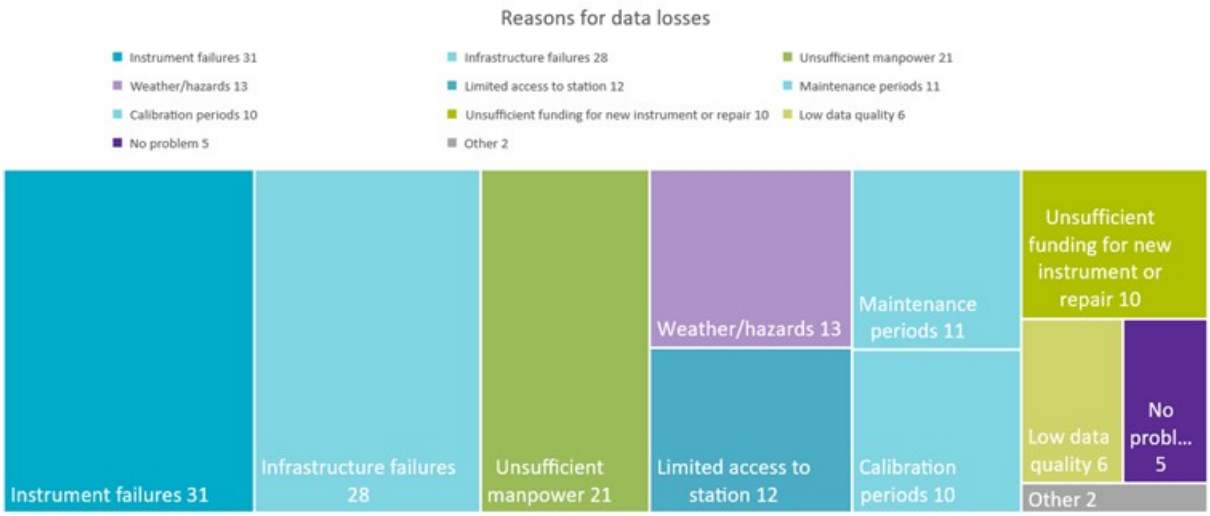


Figure 1.8: Reasons for data losses.

Evidence for Criterion 4: Innovation management

Table 1.9: Evidence material for subcategory 1.2, criterion 3

Documents available online	**KPI**
RINGO project deliverables WP1. Del. 1.3. An ICOS flask sampling protocol based on historical time series and high-resolution footprint modelling Del. 1.5. Scientific and technical concept for the integration of ground-based greenhouse gas remote sensing into ICOS Del. 1.7. Revised Scientific-Technical protocol for standardized biomass observations in ICOS by means of ground LIDAR WP3. Del. 3.2. implementation and technical realisation of atmospheric measurements on the three commercial Ships of Opportunity platforms Del. 3.5. Protocol for non-CO_2 eddy covariance measurements, QA/QC, data processing and gap-filling	7
ICOS RI Annual Work Report 2017	7
ICOS RI Annual Work Report 2018	7
ICOS RI Annual Work Report 2019	7

Documents available in the Material folders	**KPI**
ICOS RI Annual Work Report 2016	7

Survey questions	Target group
35. ICOS is able to take up technical innovations. 36. Which new technologies should be considered for future developments in ICOS? 37. ICOS RI should develop an overall strategy for the stations and the Central Facilities to have access to additional scientific projects and instruments. 38. What kind of additional projects and instruments would you suggest?	Station PIs
28. ICOS is able to take up technical innovations. 29. Which new technologies should be considered for future developments in ICOS? 30. My Central Facility investigates new technologies and prepares for their implementation in ICOS. 31. What new technologies does your Central Facility investigate and prepare for implementation in ICOS? 32. ICOS RI should develop an overall strategy for the stations and the Central Facilities to have an access to additional scientific projects and instruments. 33. What kind of additional projects and instruments would you suggest?	CF coordinators

New technologies and instruments as well as new network approaches and ICT solutions have permanently been taken up during the implementation and will also be monitored during the operational phase. The thematic centres have responsibilities in instrument testing, described in their contracts with ICOS and reported in their annual reports. A table listing detailed innovation steps is provided in the online material. A few highlights are listed here:

- ATC is testing standard instruments before deployment in the ICOS network. These tests have become a benchmark and are now taken into account by industrial manufactures like Picarro and LGR improve their performance and to guarantee they are in conformity with ICOS specifications. In terms of technology watch, several instruments, not qualified so far in ICOS, were tested using the same benchmark to allow comparison.
- The Central Analytical Laboratories (CALs) developed an ICOS flask sampler and flask sampling protocol. Flask sampling is conducted at all ICOS class-1 stations with subsequent analysis for greenhouse and other trace gases as well as for isotopic analysis of CO_2 in the CAL. There are three main aims for regular flask sampling:

  1. Use flask value for comparison with trace gas components measured in situ at the station (CO_2, CH_4, CO, (N_2O)). This comparison shall provide an ongoing quality control of the in situ measurements.
  2. Obtain data of components not measured continuously at the station, such as SF_6 or H_2, but also stable isotopes of CO_2 or O_2/N_2: Here we aim at monitoring their large-scale representative concentration levels to allow estimating their continental fluxes with help of inverse modelling.
  3. Analysis of ^{14}C in CO_2 to allow determining the atmospheric fossil fuel CO_2 component ($ffCO_2$) and with help of these observations and inverse modelling to estimate the continental fossil fuel CO_2 source strength.

  Based on footprint model simulations the sampling strategies have been investigated and optimised.

- ETC and PIs from the Ecosystem community worked on the synchronisation between the sonic anemometer and the gas analyser and improved commercial and non-commercial data acquisition system to avoid digital clock drifts at ICOS ecosystem sites.
- OTC has been constantly working on the integration of pCO_2 measurements into autonomous marine vehicles. They designed, installed and tested a new system during the RINGO project and organised a Saildrone campaign along ICOS fixed stations in summer 2020.

After successfully testing the pathway, the implementation has so far been defined case by case. E.g., the new FTIR spectronous Ecotech instrument was tested at the ATC and other places within the MSA community (including the CRL). Once it met the ICOS atmospheric specifications (it took a few years with some instrumental developments and fine tuning of operating mode/calibration), it was accepted as an ICOS compliant instrument. ICOS atmospheric specification is validated by the ATC and the Atmosphere MSA. If the cost incurred can be reimbursed in the existing budget, the operational implementation proceeds. In the case of the FTIR, that means the ATC has to develop a whole new data process for this particular instrument (this development is in progress at the ATC). If there is a budget issue, it should be taken up at the ICOS GA.

Core results from the survey

Both PIs and CFs were asked, which new technologies should be considered for future developments in ICOS? The answers can be roughly grouped to new in situ technologies, satellites, ground based remote sensing and profiling instruments (such as lasers, AirCore, TCCON and drones) and to new processing of existing data. Distribution in these categories is seen below, satellite technologies being the largest group in both.

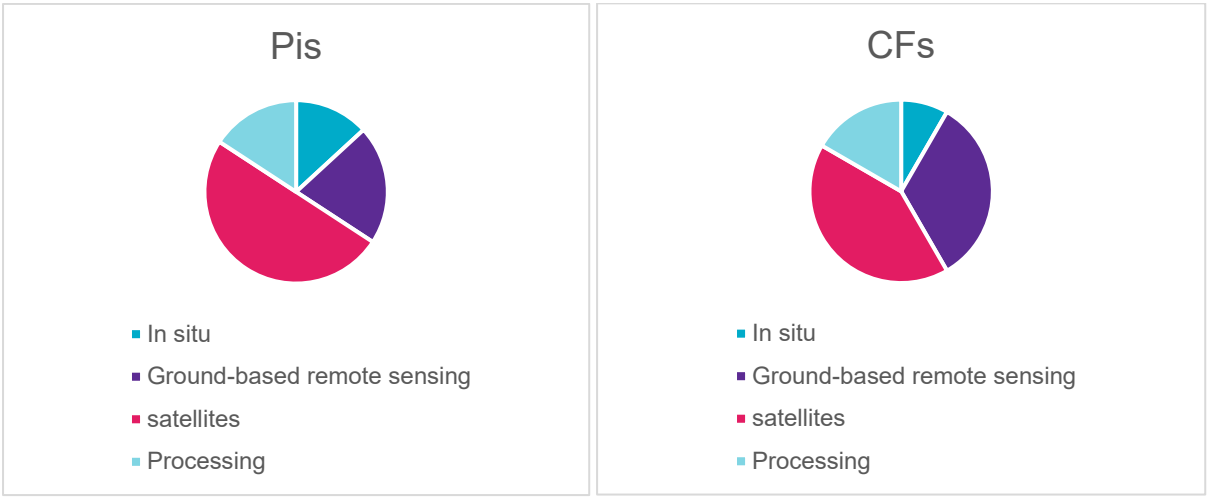


Figure 1.9. Which new technologies should be considered for future developments in ICOS? Suggestions of station PIs (left) and Central facility coordinators (right) grouped by main technology.

1.3 Data Life Cycle

Rationale

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

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?

Criterion 1: Data workflows are well defined and effective

Does documentation exist for all stages of the workflow? Are the responsibilities of all responsible parties clear and documented?

KPI's for Criterion 1

KPI 8: Definitions of data workflows

Completeness of data workflow descriptions.

Criterion 2: Data are timely

What are the criteria for timeliness and how are they defined for the different user needs? Have all the relevant data products from labelled stations arrived in time and how is this monitored?

KPI's for Criterion 2

KPI 9: Timeliness of data provision

Timeliness of NRT and L2 data. According to the contracts between ICOS ERIC and Thematic Centres the L2 products need to be delivered at least once per year with a maximum delay of about 6 months after the end of the calendar year. Near Real Time data should be delivered within 24 hours after the measurement period end, in the case of data from SOOP that have no satellite communication, data can only be transferred when harboured, which can cause a delay of several weeks.

Criterion 3: Data are compliant with FAIR principles

KPI's for Criterion 3

KPI 10: Data compliance with FAIR principles

This is a numeric indicator defined by the number of FAIR principles that ICOS conforms to.

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

KPI's for Criterion 4

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.

This is a numeric indicator defined by the number of services for users.

Evidence

Evidence for Criterion 1-4

Table 1.10: Evidence for subcategory 1.3

Documents available online	KPI	Criterion
Automatic processing of atmospheric CO_2 and CH_4 mole fractions at the ICOS Atmosphere Thematic Centre	8	1
Identification of spikes associated with local sources in continuous time series of atmospheric CO, CO_2 and CH_4	8	1
A robust data cleaning procedure for eddy covariance flux measurements	8	1
An online tool for data reduction and quality control of surface ocean fCO_2 data	8	1
ICOS Handbook	8, 11	1, 4
Other materials and links	**KPI**	**Criterion**
https://www.icos-cp.eu/data-products	9	2
https://www.icos-cp.eu/data-services	11	4

Documents in the Materials folder	KPI	Criterion
ICOS Data & lifecycle slideshow	8, 11	1, 4
Core Trust Seal application	10	3
Carbon Portal concept paper	8, 10	1, 3
FAIRness evaluation of Carbon Portal by external expert Markus Stocker	10	3
The ICOS improved data lifecycle	8, 10	1, 3
ICOS data services list	11	4

Criterion 1: Well defined and efficient workflows

The Thematic Centres process the raw data from the stations and produce daily automatically controlled Near Real Time (NRT) data and release at annual intervals final quality-controlled Level 2 (L2) data sets for all labelled ICOS stations. Data processing and quality control including the determination of measurement uncertainties and data flagging is described by the peer reviewed publications by the Thematic Centres.

As soon as the stations produce the raw data files or as soon as they are received by the Thematic Centres these are ingested at Carbon Portal without any human intervention. In addition, the Thematic

Centres ingest their NRT and L2 product files directly to Carbon Portal together with all the relevant metadata through instant transfer by the same central ingestion routines.

The implementation of the ICOS CP central repository and its integration with the (meta)data flows from the networks and domains is described in the Improved ICOS Data Lifecycle document (see evidence table). The document describes the data and metadata flow between the elements of ICOS. The procedures make sure that all data always passes through the Carbon Portal through automated and well constrained procedures under strict protocol and that any ICOS data is always persistently identified, associated with the required metadata and stored in the trusted repository.

The upload procedure is designed to only allow data of known type for that account that is accompanied with the correct metadata that includes provenance. All data is at ingestion checked for integrity, consistency and conformity with the expected data format as much as possible and only accepted when all conditions are met. Immediately at acceptance a copy of each data object is streamed to the trusted repository.

Table 1.11: Survey questions related to subcategory 1.3

Survey questions related to Criterion 1	Target group
39a. Workflows/data flows in ICOS are well defined 39c. Workflows/data flows in ICOS are efficient 40. If you disagree, can you identify the bottlenecks? 41. As a station PI, I am sufficiently supported by the Central Facilities (Thematic Centres, Central Analytical Laboratories, Carbon Portal). 45. The data submission system provided by the Carbon Portal/Thematic Centres is of high quality. 46. What could be improved? 47. Are there any gaps in Quality Assurance/Quality Control (QA/QC) procedures and data processing? 48. The ATC communicates data quality problems sufficiently to my station. 49. The ETC communicates data quality problems sufficiently to my station. 50. The OTC communicates data quality problems sufficiently to my station. 54a. The ICOS data life cycle has improved Quality of the data	Station PIs
39. Are there any gaps in Quality Assurance/Quality Control (QA/QC) procedures and data processing? 43a. The ICOS data life cycle has improved Quality of the data	CF Coordinators
10a. Workflows/data flows in ICOS are well defined 10c. Workflows/data flows in ICOS are efficient 11. If you disagree, can you identify the bottlenecks?	Focal Points RI COM General Assembly

Core results from the survey related to Criterion 1

The question 39a whether workflows are well defined is answered positive to neutral. The more positive answers are received in the order from Focal Points to RICOM to GA to PIs to Central Facilities. The efficiency of the workflow in question 39c is evaluated overall a little less positive to neutral but in the almost reverse order of the previous question. The persons actually involved in using the data flows, CF and PIs thus see their own role more positive in efficiency but also see more unclear sides of the data flow.

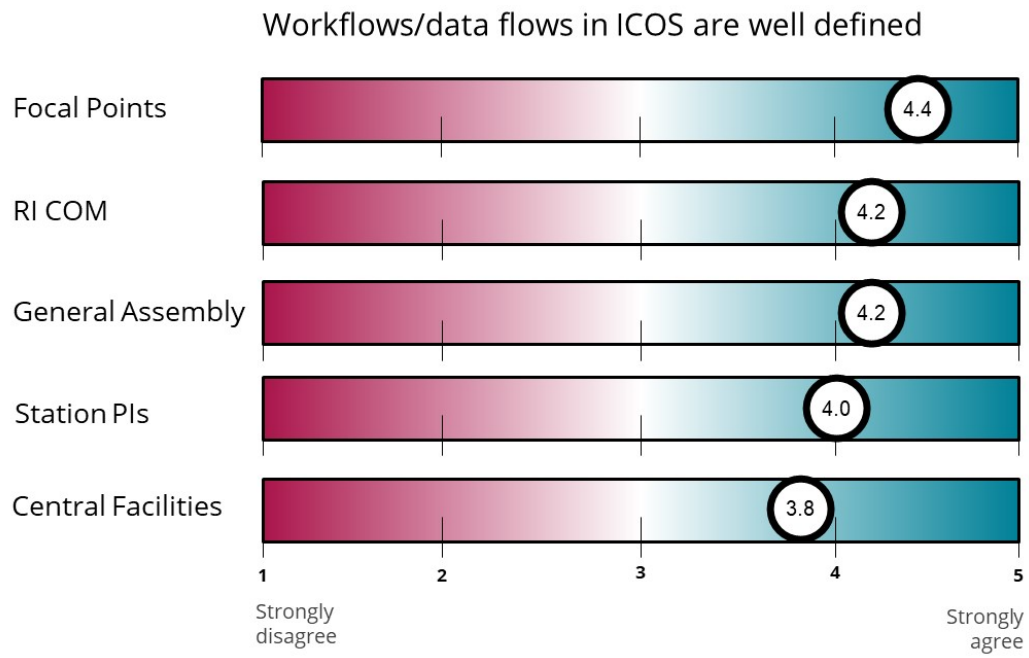


Figure 1.10: Survey results on how well the workflows in ICOS are defined.

PIs submitted many comments on the complexity of the BADM metadata system at ETC and delays in the processing of this metadata and upload of manual data.

Only 4% indicate receiving insufficient support from the central facilities, but another 14% can't agree or disagree to this.

The data submission systems receive considerable criticism with regard to user friendliness, but from the responses it cannot be derived which facility/ies this concerns. No clear gaps have been identified by the PIs in the QA/QC procedures.

The communication of data quality problems with the Thematic Centres is not applicable for the majority of PIs, most probably because this has not been needed (yet). From the PIs that answer the question, almost all answer positive to neutral for all domains.

Most respondents in all groups consider that the data lifecycle has improved the quality of the data, 30% of the PIs and only 7% of the CF coordinators are neutral.

Criterion 2: Timeliness

As the basic condition of ICOS data is that only stations that have received the ICOS label can produce ICOS data, the first official release of ICOS Level 2 data was released in summer 2018 for Atmosphere. In 2019 the first Level 2 releases from Ocean and Ecosystem followed together, with NRT data streams from Atmosphere. The Ocean domain started NRT data streams in 2020. All Level 2 releases since 2018 were yearly and contained data with only 1-3 months delay with the release date. Atmosphere NRT data

streams have a delay of max 24 hour and for Ocean this depends on the time that data transfer is possible.

Table 1.12: Survey questions related to Subcategory 1.3

Survey questions related to Criterion 2	Target group
39b. Workflows/data flows in ICOS are Fast. 40. If you disagree, can you identify the bottlenecks? 43. My station data is submitted in time and with good quality. 44. If you disagree, where are the problems? 54b. The ICOS data life cycle has improved Timeliness of the data.	Station PIs
36. I receive station data and other input from Principal Investigators in time and in the expected quality. 37. If you disagree, what are typical problems? 38. The capacities and resources of the Thematic Centres/Central Analytical Laboratories are sufficient to secure timely data processing/data delivery. 43b. The ICOS data life cycle has improved Timeliness of the data	CF Coordinators
10b. Workflows/data flows in ICOS are Fast. 11. If you disagree, can you identify the bottlenecks?	Focal Points RI COM General Assembly

Core results from the survey related to Criterion 2

The speed of the workflow is evaluated as generally positive to neutral for all groups of respondents, but some PIs disagreed or even strongly disagreed. Most comments were on the speed of processing metadata and manual data at the ETC. Also, quite a few PIs commented that they would like to see more frequent L2 releases and with a smaller delay (up to a month). Both the facilities and PIs see some problems in the station data timely submission and quality, but this concerns only about 10%, indicated reasons are lack of manpower or that the station is still in the process of labelling.

46% of PIs do not see improvement of the timeliness of the data due to the ICOS data life cycle. CF coordinators answered very positively to this question.

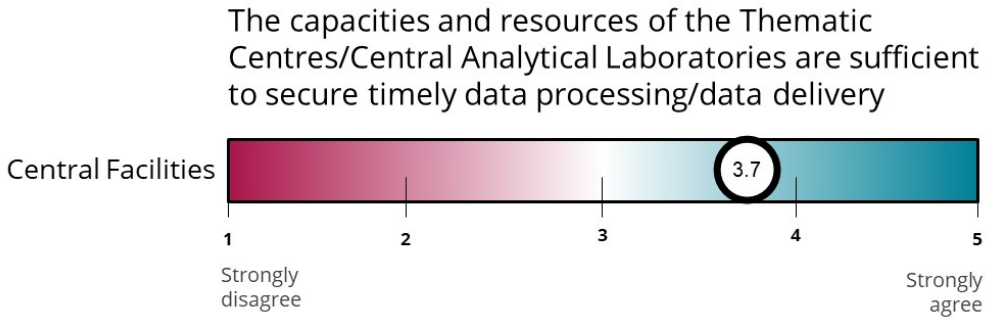


Figure 1.11: Survey result of adequacy of capacities and resources for timely data delivery.

Criterion 3: Compliance with FAIR

In 2016, the 'FAIR Guiding Principles for scientific data management and stewardship' were published in Scientific Data. The authors intended to provide guidelines to improve the Findability, Accessibility, Interoperability, and Reuse of digital assets. The principles emphasise machine-actionability (i.e., the capacity of computational systems to find, access, interoperate, and reuse data with none or minimal human intervention) because humans increasingly rely on computational support to deal with data due to the increase in volume, complexity, and creation speed of data.

The FAIR principles consist of a set of 13 criteria that refer to both metadata, data and infrastructure and most principles require that conditions have to be met in all these three aspects for the principle to work.

It is important to notice that the FAIR principles are indeed principles, meant to serve as guidance and not absolute requirements to which you can be compliant yes or no. There are many ways to comply with the criteria and in some cases, the machine interfaces that would rely on the principles are still developing, do not exist yet, or differ vastly for different use cases which makes design choices difficult or impossible. In a world of fast developing digital infrastructure, an agile approach is required.

The ICOS data processing systems in the domains have been developed for a large part before 2016 and are based on state-of-the-art technologies from the 1980's or 1990's, modernised and scaled up gradually. By the time the FAIR principles were minted, the domain data services of ICOS had already been developed and for most part were already operational. The Carbon Portal serves as the FAIRification layer on top of these excellent high quality data processing services that serve the national networks and as data interface to the outside world.

The Carbon Portal was conceptualised in the period 2012-2014 and the CP concept paper (see evidence list) was accepted by the ICOS Interim Stakeholder Committee in 2014, which is the year the development started. Many of the FAIR principles are met quite naturally by the design concepts of the Carbon Portal, which is based on a so called linked open data approach that follows the W3C recommendations (https://www.w3.org/TR/ld-bp/).

All ICOS data, from raw data up to the final, quality-controlled Level 2 data and contributed elaborated and ancillary data is identified by persistent identifiers based on cryptographic encryption technology to make sure that data is immutable over the whole data lifecycle. All metadata is stored in a so-called 'triple store' in RDF format where each statement is logged with time to enable to restore the state of the metadata to any point in time. The ontology is based on semantic web technology and modelled in OWL. An open SparQL endpoint at https://meta.icos-cp.eu/sparql exposes the complete (read-only) ontology (http://meta.icos-cp.eu/ontologies/cpmeta/) to the users and forms the back-end for almost all metadata and data related services of ICOS CP.

All data objects receive a PID at ingestion, and the resolution of the (Handle through ePIC) PID leads to a machine and human readable so-called 'landing page' that provides the most relevant metadata of the data. Only selected accounts from Thematic Centres and Carbon Portal have authorisation to ingest data and modify metadata.

The data object landing pages are generated on the fly and use the ontology to provide the most up to date metadata belonging to the objects. The ontology supports versioning, deprecation of older versions and collections. Access to all metadata and data is open, free and based on standard internet protocol http(s) transfers. Metadata is licensed by CC0 and the ICOS data is licensed under CC4BY. Contributed data can be licensed under any well-known license.

All software developed by ICOS CP is open source and wherever possible, uses only open-source libraries for its dependencies. All source code is available from the CP Github repository under a GPL-v3 license.

All data objects are findable through the SparQL endpoint, and through SparQL and the linked open data system and the landing pages, users can explore all metadata of the data in detail. User friendly Web interfaces have been created to explore the data and metadata and specifically find, select, preview and download the data. The main entry point for users looking for ICOS data in all detail is the portal app at https://data.icos-cp.eu/portal and the most recent main data products from ICOS can be explored from https://www.icos-cp.eu/data-products.

The expert review by Markus Stocker of the ICOS data Lifecycle document concluded that the ICOS data system conforms with 9 out of the 13 FAIR principles and recommends some improvements to especially the Interoperability aspects. These possible improvements already had been identified as part of the ENVRIFAIR FAIRification process and are under way.

Table 1.13: Survey questions related to subcategory 1.3

Survey questions related to Criterion 3	Target group
53. The Carbon Portal adds notable value to submitted data by improving data interoperability and reusability. 54c. The ICOS data lifecycle has improved Interoperability of the data	Station PIs
42. The Carbon Portal adds notable value to submitted data by improving data interoperability and reusability. 43c. The ICOS data lifecycle has improved Interoperability of the data	CF Coordinators

Core results from the survey related to Criterion 3

Most respondents who answered on the added value of CP for improving data interoperability and reusability were positive with more neutral reactions among the PIs than in the other groups.

All respondents see very positive improvements in interoperability of data from the ICOS data lifecycle.

Criterion 4: Carbon Portal is single point of access

As shown in the Data Lifecycle document, all ICOS data flows through and is curated by the Carbon Portal and is there combined with the relevant metadata. Through a set of Web and API (machine usable) services users have free and easy access to all data and metadata. The list of services built on top of the core SparQL and data services is already large and summarised in the ICOS data services list. More detailed descriptions and introductions and links can be found on the CP part of the ICOS website.

Users are encouraged to publish their results that (partly or whole) are based on ICOS data through the Carbon Portal as elaborated, enriched, products. Through a set of collaboration tools, the Carbon Portal gives easy access to the data and assists the ICOS community of data providers, data managers and scientists (sometimes the same people in different roles) in their collaboration and development of carbon cycle science.

Carbon Portal also connects ICOS to the European and global initiatives with focus on data sharing like COPERNICUS, FLUXNET, SOCAT and WMO GAW. CP also provides support to scientific initiatives like EUROCOM, TransCOM, IG^{3}IS, the MEMO2 Marie Curie network, the Drought and Winter2020 initiative by (co) organising workshops and symposia, giving access to mail lists, the ICOS Fileshare for collaborative data and document sharing and most importantly Jupyter notebooks. These Jupyter notebooks are now widely used by the modelling community for multi-model ensemble evaluation, measurement strategy development in Atmosphere and evaluation of ICOS data in general. The Jupyter notebooks open the way to cloud based and well documented scientific workflows, uncovering endless

opportunities for scientific discoveries using ICOS data, while preserving the attribution to the ICOS data providers for their efforts in providing the high-quality observations.

The open access to ICOS data combined with efficient, instantaneous and machine-to-machine-oriented workflows using robust scalable cloud services has already led to a strong increase in use of ICOS data and uptake in scientific products. Also, initiatives like the Global Carbon Project and local networks now use Carbon Portal to publish their scientific results.

Table 1.14: Survey questions related to subcategory 1.3

Survey questions related to Criterion 4	Target group
51. I have searched data provided by my station in the Carbon Portal. 52. If yes, data by my station was easy to find in the Carbon Portal. 55. The efforts to make the ICOS data citable ensure the credits to me as a station PI.	Station PIs
40. I have searched data provided by my Thematic Centre in the Carbon Portal. 41. If yes, data by my Thematic Centre was easy to find in the Carbon Portal. 44. The efforts to make the ICOS data citable ensure the credits to me.	CF Coordinators

Core results from the survey related to Criterion 4

A small minority of the PIs have tried to find their station data in the ICOS Carbon Portal and a large minority had some problem with the ease of use. From the TC coordinators the majority had tried to find data for their domain and their success rate for easy access was considerably higher.

A small percentage of PIs (8%) do not see that the efforts of ICOS in making the data citable as of value to them, but the majority opinion is positive to very positive. CF coordinators see considerably less benefit for the citation to them.

Category 2: Financial Management

2.1. Core Funding

Rationale

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.

Objective

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.

Criterion 1: Status of core funding

Is the core funding amount in line with operations? Are measures in place to monitor the mid-term financial situation and are risk mitigation methods in use?

KPIs for Criterion 1:

KPI 12: Amount, trend and volatility of core funding

The KPI monitors the level of funding received by the RI while monitoring the trends in the funding. The KPI also takes into account volatility of the funding and how this may impact the RI. Overall, the goal of this KPI is to monitor the sufficiency of core funding in all parts of the RI.

KPI 13: Equity ratio

The KPI monitors the funds available in the RI and how much of the RI's assets are funded by equity (through retained earnings) rather than debt. The ratio is used to assess the company's long-term ability to pay its liabilities as well as monitor its financial stability and risk. The ERIC, as a legal entity, can calculate the ratio through its annual financial statements. The Central Facilities and National Networks do not have their own separate legal financial statements so the calculations are done through artificial measures that are backed by real accounting figures.

KPI 14: Mid-term financial sustainability

The Mid-term financial situation allows for the strategic development of ICOS RI. Adequate funding enables the development of the Thematic Centres. The level of national funding must always be reviewed before the start of the new five-year period and updated annually in the context of budgeting.

Evidence

Table 2.1: Evidence material for subcategory 2.1 Status of core funding

Documents in the Material folders	KPI
Central Facilities cooperation agreements (ATC) (CRL) (ETC) (FCL) (OTC) (CP)	12, 13, 14
Financial Rules (ICOS IFR 20160316 APPROVED.pdf) (Approved Terms of Reference_Financial Committee.doc)	12, 13, 14

Budgets 2018, 2019, 2020, 2021	12, 13, 14
Financial report ICOS RI 2016	12, 13, 14
Financial statement and Auditor's report (translated version of official report in Finnish) 2016, 2017, 2018, 2019	12, 13, 14
Financial Reports for ICOS ERIC 2016, 2017 (2018 forward ERIC & RI report merged)	12, 13, 14
Five- year financial plan 2020-2024 (plan)	12, 13, 14

Documents available online	**KPI**
ICOS ERIC Statutes (Statutes)	12,13,14
Financial report ICOS RI 2017, 2018, 2019	12,13,14

Survey questions related to subcategory 2.1	**Target group**
27a. In general, the financial resources of ICOS are sufficient. 27b. In general, the financial resources of ICOS are sustainable. 27c. In general, the financial resources of ICOS are well-distributed between the different parts of ICOS. 28. I am sufficiently informed about the financial situation and management of ICOS RI. 29. I am sufficiently informed about the use of resources provided to ICOS RI. 30. In which field would you prefer to be better informed or to improve management? (Open question) 31. The budgeting and financial reporting systemin ICOS is comprehensive and feasible. 32. What could improve? (Open question) 33. A centralised management of unspent funds in a common reserve fund would improve the ability of ICOS RI to react to crisis situations.	General Assembly
45a. In general, the financial resources of ICOS are sufficient. 45b. In general, the financial resources of ICOS are sustainable. 45c. In general, the financial resources of ICOS are well-distributed between the different parts of ICOS. 46. The budgeting and financial reporting system in ICOS is comprehensive and feasible. 47. What could be improved? (Open question) 48. A centralised management of unspent funds in a common reserve fund would improve the ability of ICOS RI to react to crisis situations.	CF Coordinators
27a. In general, the financial resources of ICOS are sufficient. 27b. In general, the financial resources of ICOS are sustainable.	RI COM

27c. In general, the financial resources of ICOS are well-distributed between the different parts of ICOS. 28. I am sufficiently informed about the financial situation and management of ICOS RI. 29. I am sufficiently informed about the use of resources provided to ICOS RI. 30. In which field would you prefer to be better informed or to improve management? (Open question)	
56a. In general, the financial resources of ICOS are sufficient. 56b. In general, the financial resources of ICOS are sustainable. 56c. In general, the financial resources of ICOS are well-distributed between the different parts of ICOS.	Station PIs

The financial management of a distributed RI is as complex as its governance structure. The obligation for funding of ICOS RI comes from the statutes: The members and observers *'pay the annual membership* (or Observer) *contribution'* and '*provide the necessary infrastructure and resources for ICOS National Network operations and ICOS Central Facilities that it hosts*.' Since ICOS ERIC is small in relation to the entire ICOS RI, and the Central Facilities and National Networks are not part of ICOS ERIC, these obligations result in different funding streams that differ in sources as well as in details of the financial management and reporting.

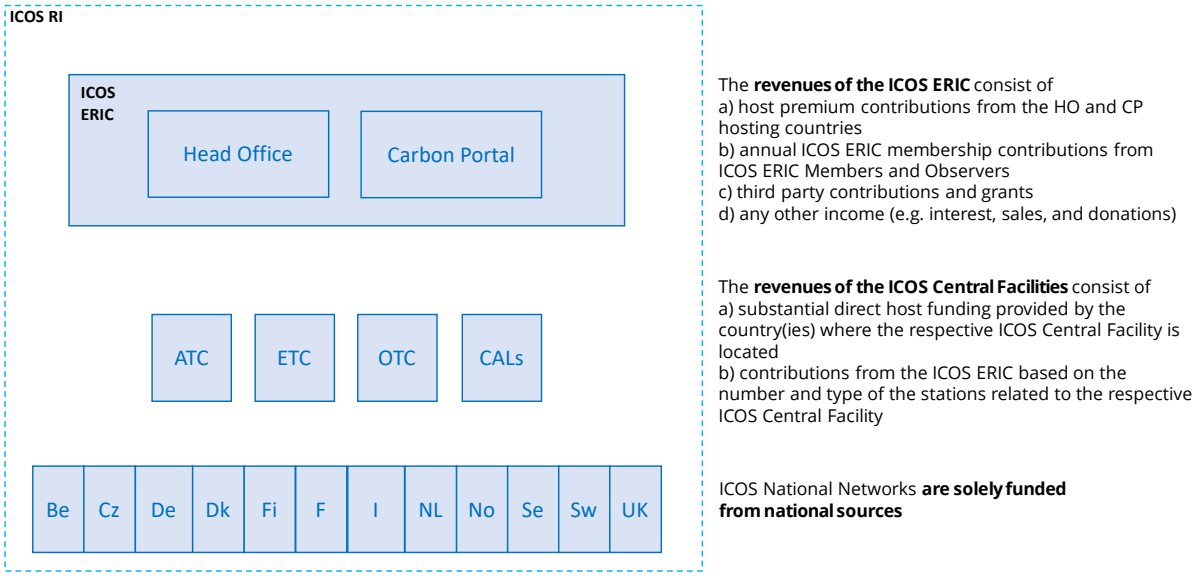


Figure 2.1: Overview of the different revenues of ICOS ERIC, ICOS RI Central Facilities and ICOS RI National Networks.

Financial rules

During the preparatory phase project (PPP) stage, the financial principles of ICOS were developed and written in the Internal Financial Rules (IFR). The current IFR were approved by the General Assembly in 2016.

Financial reporting system

The ICOS financial reporting system was developed during the years 2016 and 2017 by the Head Office and Central Facilities. While all parts of ICOS RI are reported and reviewed during the spring General Assembly, the ERIC has more stringent demands for reporting in general. The ERIC, as a legal entity, is required to be audited in its host country, Finland. The audit is used as a tool to ensure the appropriate legal handling of ERIC funds provided by the host premium members and the member and observer countries of ICOS. The audited figures are then transferred to the template that has been approved by the General Assembly.

As the Central Facilities are not stand-alone legal entities, they have different requirements and thus follow the rules of their host institution and country on accounting and audits. The RI does not require each Central Facility to be audited, but trust that the host institutions are audited each year individually. The RI trusts in the Central Facilities and their host institutions to provide accurate information when reporting their finances to the General Assembly in the specified templates. In case of any discrepancies, the Head Office and/or the General Assembly can request clarifications on the reported figures. The Central Facilities report personnel costs and the related efforts in person months (PM) but don't relate these to specific tasks.

In addition to the ERIC and Central Facilities, the National Networks are requested to provide their financial information to the General Assembly in the approved templates. These reports are also based on trust without ICOS-required audits. The National Networks must also follow the accounting and audit requirements of their host institution and country.

After the ERIC's audit and before the General Assembly, all financial reports of the ICOS RI are reviewed in the Financial Committee. The committee discusses the results and may ask for further details for example, in cases of large deviations from the budgeted figures. After clarification, the committee gives its recommendation for further action and may ask for changes in the financial reports presented to them before the General Assembly.

The financial reports and the ERIC audited Financial Statements are then presented in the Spring General Assembly. The General Assembly approves the ERIC financial report and discharges the Director General of financial liability for the previous year. In case the ERIC report is not approved, the General Assembly can request further information and/or corrections to the financial report, but not the audited Financial Statements. The financial reports provided by the Central Facilities and National Networks are reviewed, but do not need the approval of the General Assembly according to the Internal Financial Rules. The General Assembly can ask for further details if needed.

In autumn, the budgeting process is done for the upcoming year. The number of stations that will be included in the membership calculation are sent to the Head Office. This allows for the ERIC and Central Facilities to plan their upcoming revenues and accordingly their expenses to fulfil the tasks stated in the work plan. The Financial Committee also plays a guiding role during the budgeting process and again may request more information. With this guidance, the budgets are presented in the autumn General Assembly. As with the financial report, only the ERIC budget needs the General Assembly's approval. The ERIC budget includes station-related contributions to the Central Facilities; the General Assembly takes note of the host contributions and the budgets. The National Networks up until now have not sent their budgets for review.

Accounting and auditing of ICOS ERIC: Accounting is handled as a purchasing service through an independent company Azets Oy. The same company also handles the payment of ICOS ERIC employees' salaries and the submission of working time reports. Azets has specific persons handling ICOS ERIC affairs.

Communication with Azets is managed by the Head of Administration and the Junior Controller. Azets also has sales and purchase ledgers, but the Head Office does not have access to these, and all account transactions are tracked through accounting exports. All Horizon2020 projects have their own cost centres with some of the projects audited at their end based on EU rules. In addition, the Academy of Finland has its own cost centre, as its funding is audited at the end of the funding period. Some large events like Science Conference also have their own cost centre.

The cost centres of Horizon2020 projects record the costs directly attributable to them. Similarly, salaries are shown in these cost centres in accordance with the Academy's calculation rule, but the figure is not directly useful in EU reporting, as it only includes the salary amounts of persons working in Finland. Annual accounting is performed on an accrual basis. Receivables are calculated for EU projects according to the cost-income principle because the periodic reporting of projects differs from the annual rhythm. A provision is made in the accounts if there is only an estimate of the invoice for the year ending, this provision is released the following year against actual payment.

The accounts of ICOS ERIC are audited once a year in accordance with the Finnish Accounting Act. The audit report will be written in Finnish, but a translation (unofficial) will be submitted at the General Assembly spring meeting. At the meeting, the Director General presents the spending of the year under review and the meeting approves the financial statements and discharges the Director General from liability for that financial year.

The audit firm of ICOS ERIC has been KPMG since 2017. The same company also carries out the separate audits required by the projects. The responsible auditor has changed after 2017. KPMG also conducts, on request, separate investigations related to e.g., Value Added Tax, for external rewards. To ensure smooth and time-saving operation the cooperation between auditing and accounting services should be based on the long-term relationships. ICOS ERIC also has its own procurement rules approved by General Assembly in 2018, which grant freedom of procurement based on the specificity of ICOS ERIC.

Accounting and auditing of the Central Facilities: The Central Facilities have the responsibility to follow the accounting rules in their host countries, without the direct supervision of ICOS ERIC. As mentioned previously, the Central Facilities are not legal entities so are thus not audited in relation to their ICOS activities separately. The Central Facilities are audited in their own host countries and based on their hosting institutions as a whole. The institutes are also participating to the Horizon2020-projects and the liability of accounting is audited through the projects based on EU regulations.

Unspent funds and their management: ICOS ERIC-Head Office's unspent funds are in the bank accounts of the Head Office (separate bank accounts for Euro and Swedish Crown) and are monitored yearly. At the end of the Financial Year, the balances of the bank accounts and other assets are reported in the Financial Statements. They are first reviewed by the Financial Committee and then reported to the General Assembly during spring, after the audited Financial Statements have been signed by the auditor (KPMG). ICOS ERIC-Carbon Portal's unspent funds are kept separately in Lund, with the exception of the Carbon Portal's common contribution which is kept at the Head Office to cover the expenses of the Director of the Carbon Portal, who is under ICOS ERIC employment. The remaining unspent funds in Lund are also reported in the spring General Assembly.

Unspent funds of the Central Facilities are managed by their host institutions. ICOS ERIC has no direct access to the Carbon Portal's or the Central Facilities' accounting systems or banking, but has the ability to request more detailed information, if necessary. During the Spring General Assembly, the unspent funds are discussed and may require further explanation from the facilities if the sums are too large. The intended use of unspent funds has to be reported to the General Assembly with the budget in the Autumn General Assembly.

Discussions about the management of unspent funds and a common reserve fund are pending and should be resolved with the approval of the updated Internal Financial Rules of ICOS RI in autumn 2020.

The attitude towards a common reserve fund is neutral or very slightly positive in the General Assembly and the Central Facilities, respectively. In the Autumn General Assembly meeting 2020, the chair of the Financial Committee will give the report of the Financial Committee.

Financial development of ICOS since 2014

Figure 2.2 shows the amounts and the trends for the core funding of ICOS RI operations. The National Networks have the highest share with increasing trend mainly due to new stations joining the network (data available from the reports 2017 – 2019). The reported revenues include funding by respective governmental programmes and in-kind contributions by the Host Institutions. The average annual revenues of the National Networks during these years have been 17.1 M€ with a small volatility (7%). The Central Facilities had on average about 5.6 M€ annual revenues with an increasing trend and a higher volatility (17%). ICOS ERIC (Head Office and Carbon Portal) had on average 2.1 M€ and also an increasing trend. The volatility was 15%.

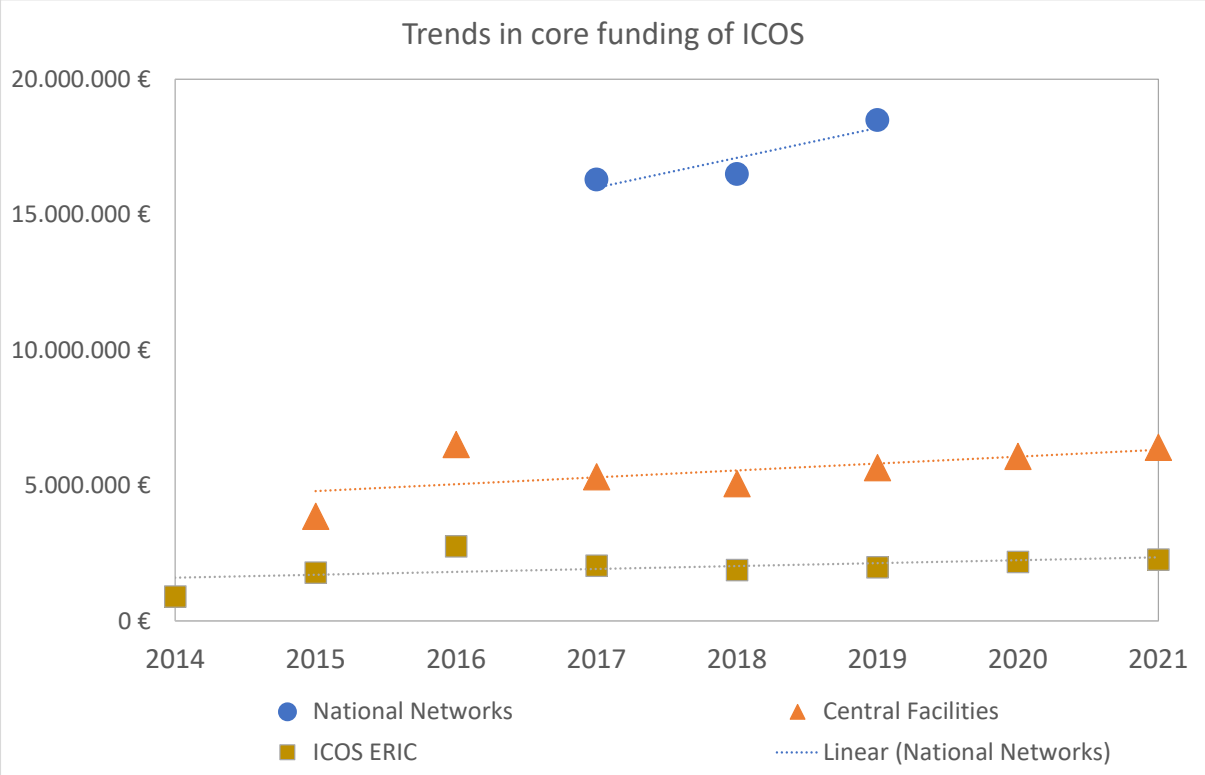


Figure 2.2: Trends in ICOS core funding since 2014

Financial sustainability of ICOS

Foreseeing the mid-term financial sustainability of the entire research infrastructure is important for the stability of its operations. ICOS ERIC works in five-year financial cycles. The transition from the first (2015 – 2019) to the second (2020 – 2024) financial cycle motivated a survey about the financial sustainability that was repeated for this evaluation.

The following paragraphs provide a brief overview on the situation. The **membership contributions** towards ICOS ERIC which comprise about 20% of the revenues of the Head Office, the Carbon Portal and the Central facilities have been fixed for the period 2020 – 2024 by a General Assembly decision in autumn 2019. They were increased in comparison to the first period (2015 – 2019) by about 2% and can be seen as sustainable until 2024.

ICOS Head Office: The larger parts of the Head Office resources are comprised of the Finnish and French Host Premium Contributions. Half of the Finnish host Premium Contribution for the second financial five-year cycle was secured through an invited proposal by the Academy of Finland in late 2019. In accordance with the decision on the Finnish Host Premium Contribution, the Finnish Meteorological Institute followed the positive review by the Academy of Finland and secured the second half for the same period. With a positive French decision early 2020, the Host Premium Contributions for the Head Office are now secured until the end of 2024. Negotiations for the next five-year period funding will be prepared in 2023.

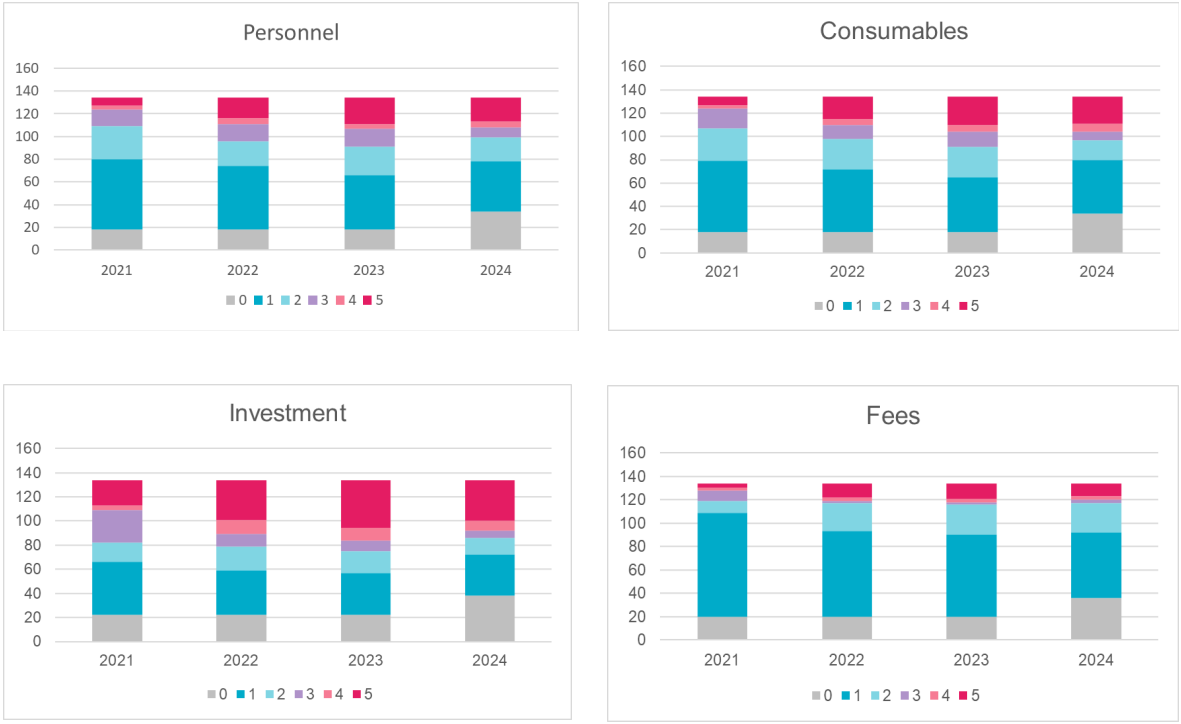
ICOS Carbon Portal: The Carbon Portal has secured its Host Premium Contribution for 2021-2024 by a funding decision of the Swedish national funding agency (VR).

ICOS Central Facilities: The sustainability of the Host Contributions towards the ICOS Central Facilities differs between the hosting countries. About one quarter of the Central Facility coordinators mentioned in the survey that they are not sustainable with increasing insecurity for 2023-2024.

ICOS National Networks of stations: The results for the different parts of the research infrastructure differ and it seems that the financial sustainability of the observational stations is weakest with large differences among the countries (see below). The worries of the Station PIs result from two facts: (i) some funding agencies tend to entirely withdraw from the funding of the operations while (ii) the Host Institutions question their engagement since they are evaluated against other criteria (scientific output, education and external funding).

Therefore, more information on the sustainability of the station funding has been collected in the framework of the evaluation. These results are collected from the information related to the 134 ICOS RI stations. Countries and stations missing from the results are represented in grey in the graphs.

The question used to answer the sustainability issue was: “Please fill in the grade of secured funding: from **“1-secured” to "5-not secured at all”** for each station, each funding class and each year”.



Figures 2.3a, b, c and d: Sustainability of station funding in categories ‘personnel’, ‘consumables’, ‘investment’, and ‘fees’.

The National Networks sent comments on their funding situation:

Belgium: The Belgian National Network is in the process of applying for funding for 2021- 2024, leading to the high uncertainty of their funding situation. The Flemish stations have some reserve left for 2021 and the outcome of the Flemish funding proposal will be known by the end of 2020. The decision and funding come 100% from the Research Foundation Flanders (FWO). The funding of the Walloon and federal stations ends at the end of 2020. The Walloon and federal government still have to decide on the funding possibilities after that. In Wallonia the decision is made by the minister for research and innovation, while the federal stations are funded through the Belgian Science Policy Office (BELSPO). The membership fees are also paid by BELSPO.

Czech Republic: The funding source is 100% the Czech national state budget managed by the Ministry of Education, Youth and Sports (MEYS) based on open call and evaluated by international peer review as a part of The Roadmap of Large Research Infrastructures of the Czech Republic. The funding is secured until the end of 2022, afterwards it will be based on the national re-evaluation results.

Denmark: The Danish Universities are obliged to continue their membership of ICOS 5 years after the present funding ends (February 28, 2021). However, this means that the universities either have to pay themselves (which Is unlikely/difficult) and/or obtain external funding. There are presently no calls for running infrastructures. Will try to obtain funding from private funding sources, there is a plan for approaching potential "investors", but the process has been delayed due to the COVID-19 situation. Most of the stations in Greenland are secured by other external funding, but the stations in Denmark are in real lack of money.

France: Long term national financial plan 2020-2024 is included in the ICOS five-year plan.

Germany: The German atmosphere stations have secured long-term funding through the German Weather Service (DWD). Some institutions running ecosystem or ocean stations receive no permanent external funding and support the stations out of their own budget which is difficult, particularly for universities.

Italy: The source of the financial contributions for the Italian National Network and their legal background are as follows: 33.5% Ordinary fund for research institutes and bodies (FOE) of the Italian Ministry of Education, Universities and Research, 63% In-kind from host contribution, and 3.5% Others

Netherlands: The operational sustainability of the Dutch stations is mainly secured through the NWO-Ruisdael infrastructure but the funding for station fees is very uncertain in the Netherlands.

Norway: The numbers chosen for the terrestrial station at Hurdal are valid under the assumption that we get the funding for phase 2 as promised by the Research Council of Norway, plus the fact that Nibio has obliged to pay the station fee for up to 5 years after the NFR project ends. For the atmosphere sites the funding is guaranteed by NILU for as long as CO_2/CH_4 are part of the national monitoring program. NILU receives money for these activities via the Norwegian Environment Agency (MDIR), hence the activities can be guaranteed as NILU in-kind contributions. We are negotiating the status of Birkenes as an ICOS station with MDIR, but NILU will almost certainly guarantee funding regardless of the outcome.

Sweden: All stations have secured funding for 2021-24.

Switzerland: Both Jungfraujoch and Davos are fully funded until July 2021 (70% Swiss National Science Foundation and 30% in kind from host universities). The proposal for subsequent funding of ICOS-CH (Phase 3, 2021-2024) has been accepted in September 2020.

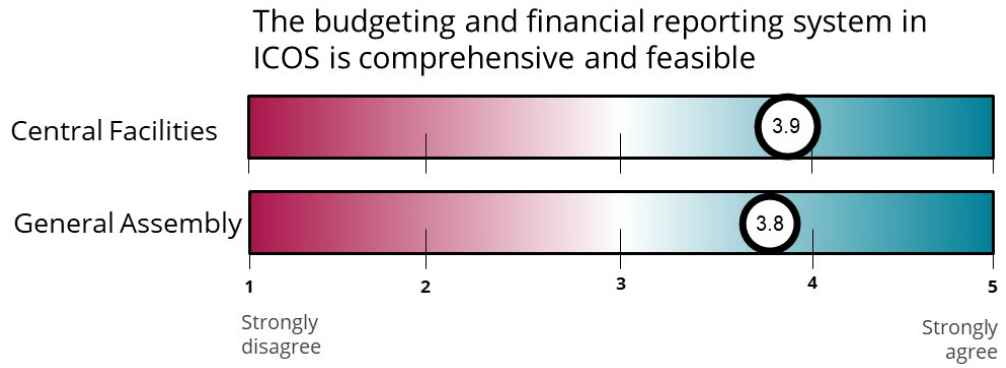
United Kingdom: *Weybourne* – Common contribution from NCAS. Station fees are paid from UEA but with money that has been awarded by NCAS. *Auchencorth Moss* – Funding is guaranteed for the next 2.5 years from NERC. After that, it is likely, but no certainties. Funds come from NERC as part of LTS-S funding, UKCEH may decide to re-allocate it but this is unlikely. *PAP Sustained Observatory* – PAP is funded

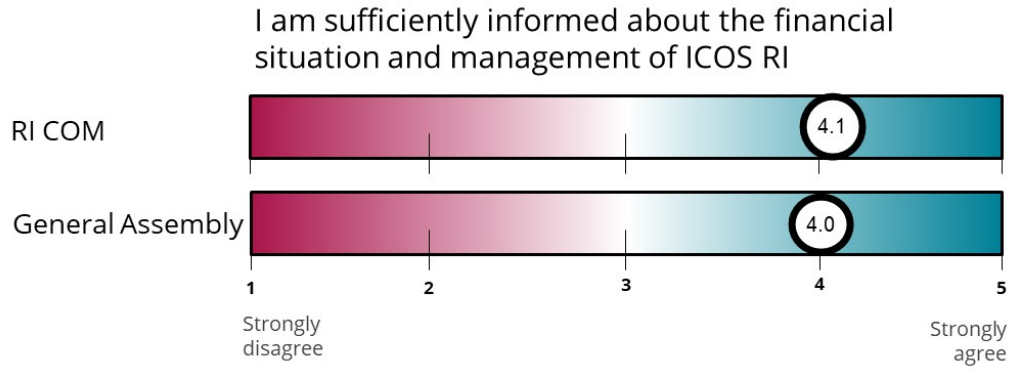
by CLASS for 2 years (with 1-year EU funding via iFADO). After that there is uncertainty over being in RIs. *UK Caribbean* – This line is no longer running due to no more funding. (Weyborne, Auchencorth Moss, PAP Sustained Observatory and UK Caribbean are names of the measuring stations in the UK.)

Core results from the survey related to Criterion 1

The General Assembly and Central Facilities agree that the budgeting and financial reporting system is comprehensive and feasible. In the written comments related to the topic, some General Assembly members required more details, in particular about the Central Facilities. The relation between spent resources and workload related to specific tasks and better explanations on discrepancies between financial planning and expenditure would help the General Assembly to better steer the work at the Central Facility when bottlenecks or under performance occur.

The results found that the General Assembly and RICOM agree that they are sufficiently informed about the financial situation and management of ICOS RI. In addition, both agreed to being sufficiently informed on the use of resources provided within the RI. The General Assembly presented lower agreement as some members would like more detailed and transparent information especially in the use of resources provided.





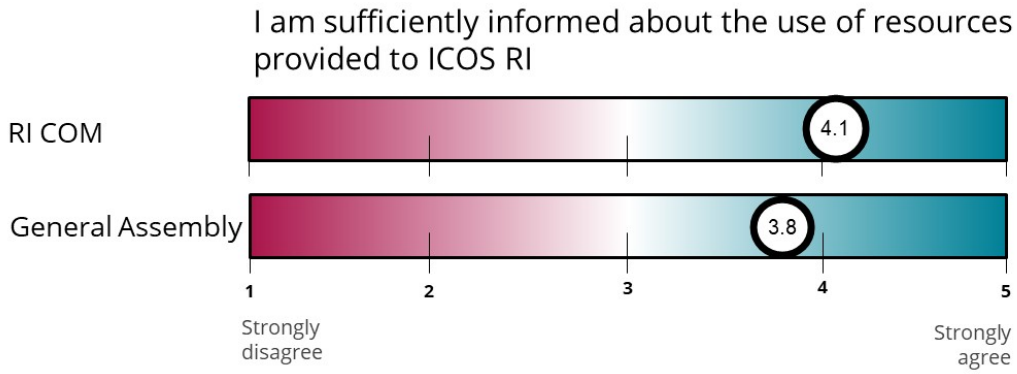


Figure 2.4: Survey results on financial management.

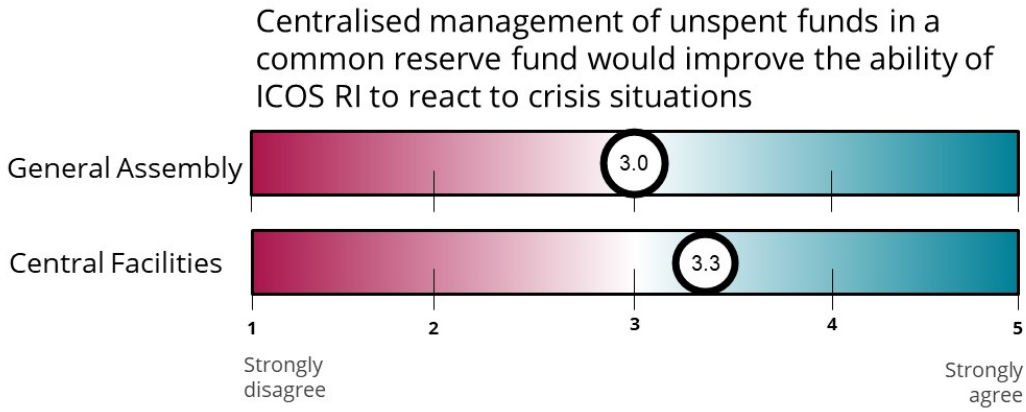


Figure 2.5: Attitudes about centralised management in a common reserve fund.

The survey results revealed differences in the perception of the sufficiency of resources between the General Assembly members (agree) on one side and the Central Facilities and Station PIs (disagree) on the other. And while the General Assembly and Central Facilities agree on the distribution of resources within the research infrastructure, the Station PIs again slightly disagree.

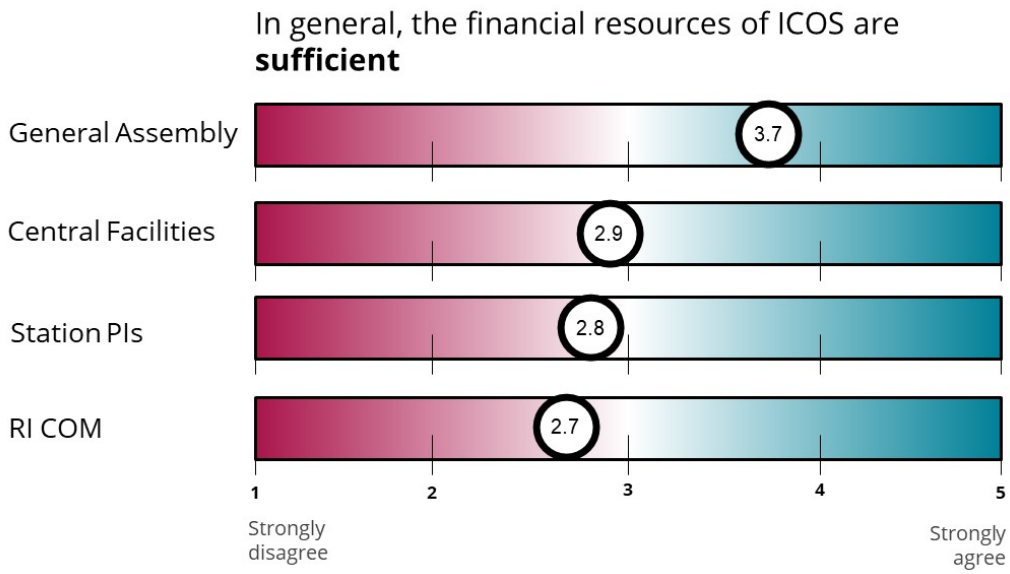


Figure 2.6: Survey results on financial resources.

The survey questions on financial resources revealed large differences between the General Assembly members on one side and the Central Facilities and the Station PIs on the other. This can be seen from Figure 2.6, survey results on financial resources 1, when asked about the sufficiency of resources. With

similar results in the sustainability question, where, in particular, sustainability is seen very pessimistically by the station PIs. In terms of distribution of resources, the General Assembly and the Central Facilities agreed that resources were well distributed, while the Stations PIs mostly disagreed (Figure 2.7).

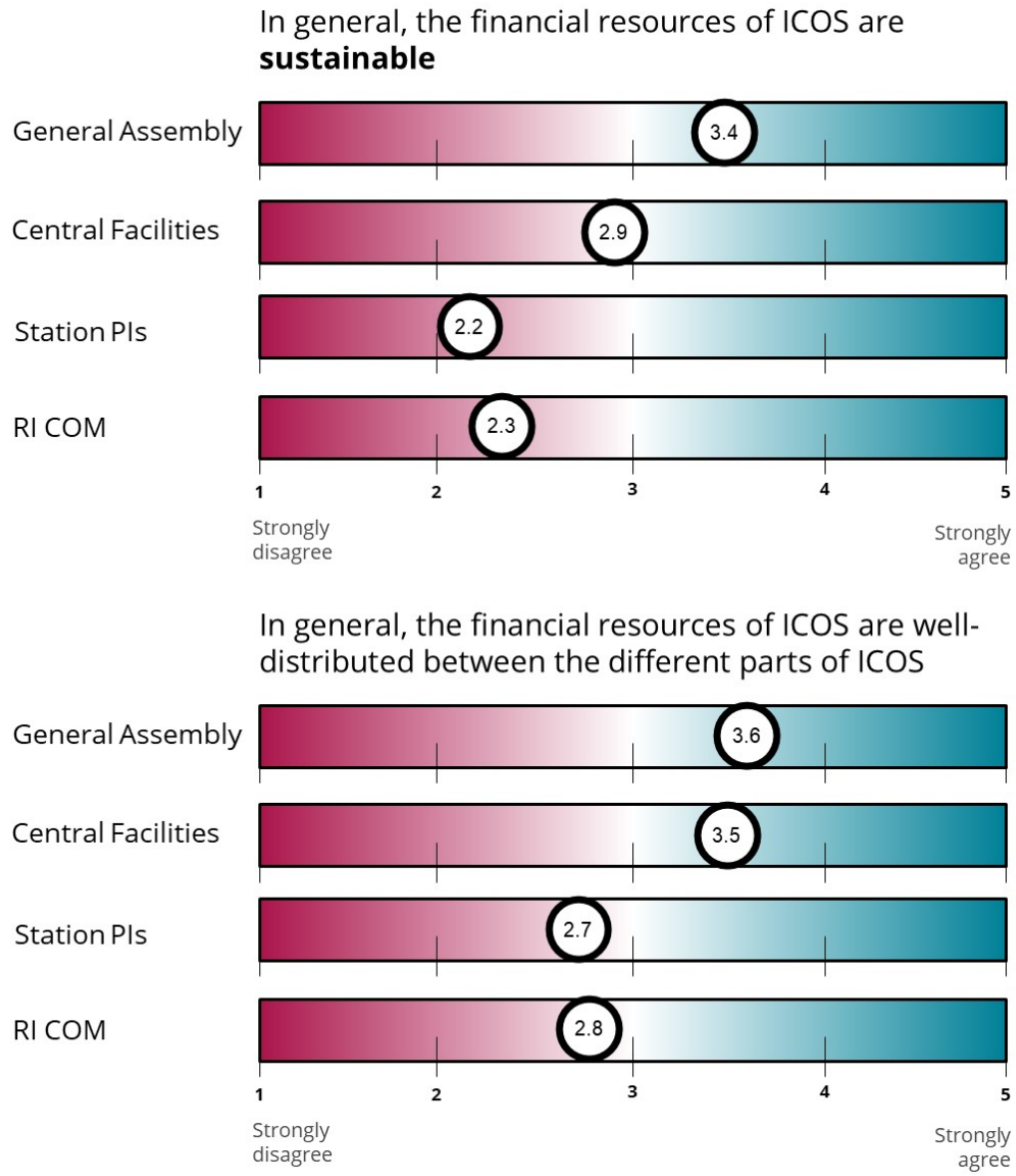


Figure 2.7: Survey results on financial resources 2.

2.2. Project Funding

Rationale

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

Objective of the project funding is the availability of resource funding and its impact on the further development of ICOS.

Criterion 1: Status of project funding

KPI for Criterion 1:

KPI 15: Amount, trend and volatility of external funding

The KPI measures the success rate of applied funding – how much funding was applied for and how much of it was granted to ICOS. The KPI also monitors the level of funding received by the RI, while monitoring the trends in the funding. The KPI takes into account the volatility of the funding and how this may impact the RI.

Evidence

Table 2.2: Evidence material for subcategory 2.2

Documents in Materials folder	KPI
Internal distribution of project funding (Excel file on project funding)	15

Survey questions related to subcategory 2.2	Target group
71./84. Externally funded projects are valuable in supporting implementation, integration, and further development of ICOS RI. 72./85. Where does the most important support to ICOS come from? (Open question) 73./86. My organisation is well integrated in planning these projects. 74./87. My organisation is well integrated in making decisions on resource distribution of these projects.	CF Coordinators Station PIs

Project funding mainly by the European Commission has been an important resource for the development of ICOS throughout the whole life cycle of the research infrastructure. Four main types of projects have been of specific benefit: (i) projects directly supporting the infrastructure development, namely the ICOS preparation phase project (2008 – 2013), ICOS INWIRE (2013 – 2015) and RINGO (2017 – 2020), (ii) the cluster projects for the environmental research infrastructures ENVRI (2011 – 2014), ENVRIplus (2015 – 2019), and ENVRI-FAIR (2019 – 2022), (iii) projects related to international cooperation, namely CoopEUUS (2011 – 2014), COOP+ (2015 – 2018), RISCAPE (2017 – 2019), and SEACRIFOG (2017 – 2020), and finally (iv) projects that are related to the European Open Science Cloud, namely EOSCpilot (2017 – 2019), EOSC Enhance (2019 -2021) and EOSC Future (2021 – 2024). In addition, ICOS has received some funding to develop COPERNICUS services and has participated in some projects of the societal challenges programme, mainly related to the development of a European Monitoring and Verification Support System for greenhouse gases, namely CHE (2018 -2020), VERIFY (2018 – 2021), and CoCO2 (2021 – 2024). ICOS ERIC has been coordinating ENVRIplus and RINGO and gained large expertise in project coordination and management. During more recent calls, ICOS ERIC has also acted as the entry point into consortia for other parts of the research infrastructure that followed either as linked third parties or full beneficiaries.

Overall funding towards ICOS in past 12 years has been almost 25M€ (~2M€/year). The main usage can be split in two categories, funding for the development of ICOS Central Facilities (~6 M€) and general development of ICOS (~10 M€). The remaining amount was related to scientific tasks, development of

services based on ICOS products or supporting the environmental domain of the research infrastructures.

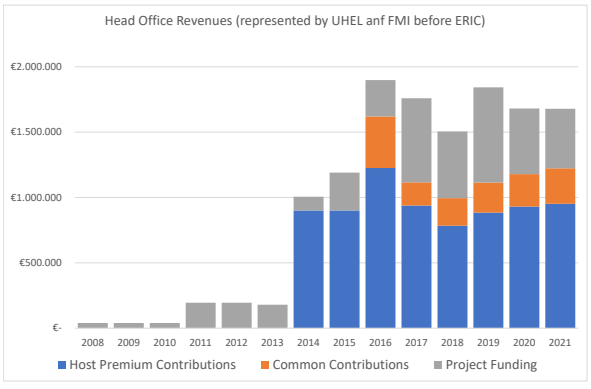
The graphs in figure 2.8 show the annual revenues of the Head Office, the Carbon Portal and the Central Facilities including an artificially calculated value for project funding. This calculation was necessary since the reporting periods for projects are very often not in line with the calendar year. Therefore, the revenues from a project were evenly distributed throughout the runtime of the project. Thereafter, the revenues from the entire project portfolio were added. The real revenues taken from a project may deviate from this theoretical number but may even out in time.

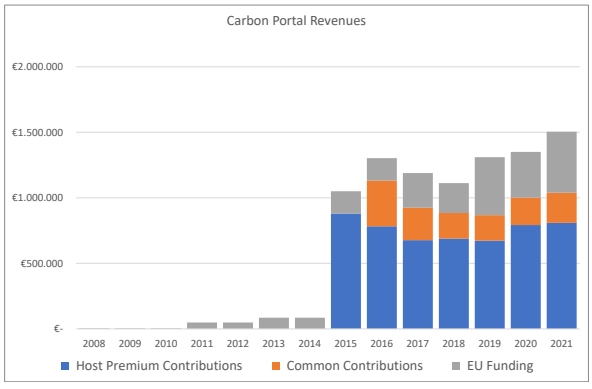
Before 2014 there were no host contributions and the design and construction were only based on project funding. During the early years, the host institutions of the ATC, the ETC and the CALs were the main actors in most projects, particularly in the ICOS Preparatory Phase Project and ICOS INWIRE which were both coordinated by LSCE (ATC Host Institution). After the establishment of the ERIC many coordinative tasks (ENVRIplus and RINGO) as well as the representation of ICOS in cluster, EOSC-related and global cooperation projects were shifted towards Head Office and Carbon Portal.

Notwithstanding, the ATC and the ETC Host Institutions kept a high amount of project funding that does not deviate much from the funding in the early years. The OTC Host Institutions increased the project funding in the years since ICOS ERIC has been established while the Host Institutions of the CALs received less ICOS-related funding.

Overall, Head Office and Carbon Portal received about 7 M€ external funding, the Host Institutions of the Central Facilities about 11.5 M€ and the Host Institutions of the National Networks and the Host Institutions of the National Networks about 6 M€.

It has to be remarked that the costs shown in the following graphs comprise design and development (in the early years) and operations (in the later years) and do not include the investments into the infrastructure itself which were mainly provided by the members in direct funding towards the stations and the Central Facilities. According to a calculation made for the latest ESFRI Roadmap the capital value of the ICOS research infrastructure achieved by these investments is about 108 M€.





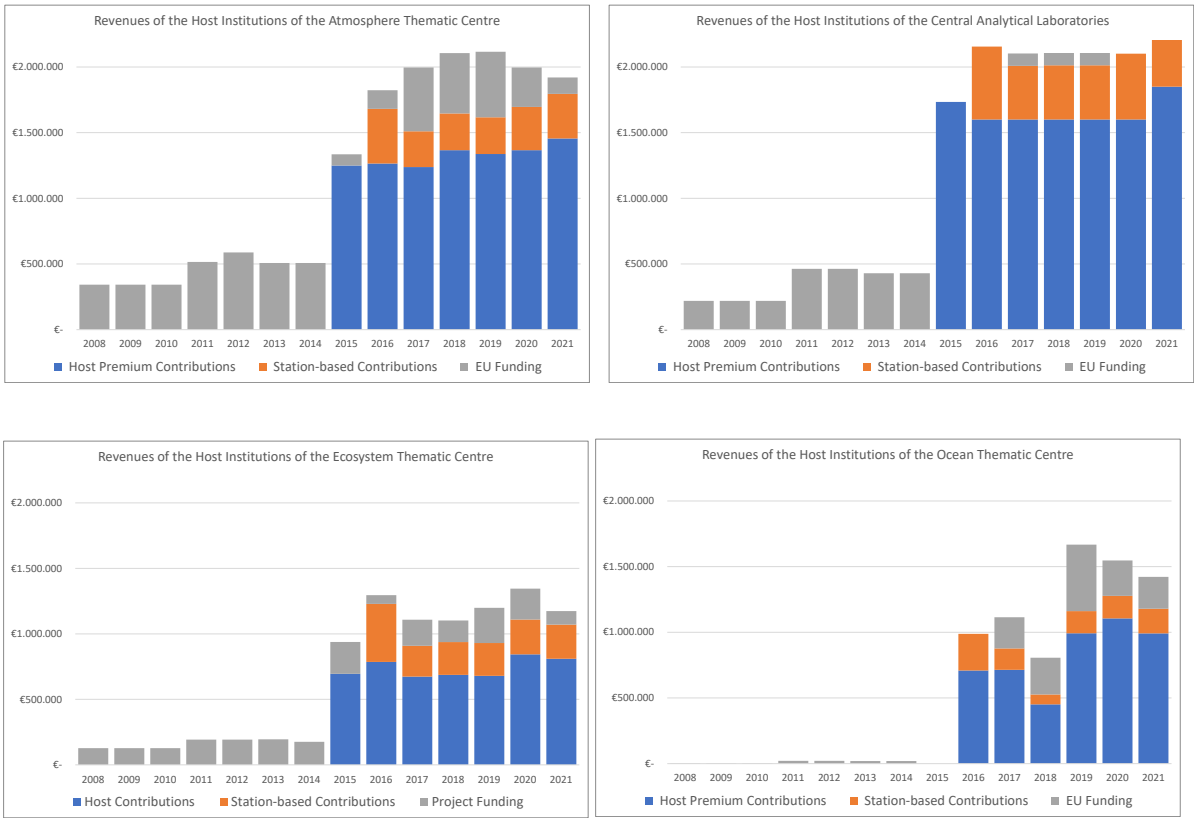
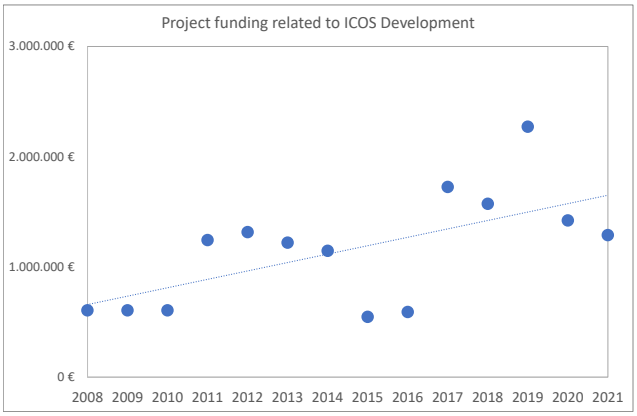


Figure 2.8: Project funding in relation to core funding for Head Office, Carbon Portal and Central Facilities.



The project funding has a high volatility (46%) but an increasing trend.

Figure 2.9: Trend in project funding towards Head Office, Carbon Portal and Central Facilities since 2008.

The internal distribution of project funding can be a sign of integration. However, the level of complexity related to this topic is extremely high since 'even distribution' might be seen as ideal but is difficult to define. Should equality be achieved between the three levels (ERIC, Central Facilities, Station Networks) or between countries participating in the RI? If the latter, should it be related to the amount of host contributions the country pays? If a country has several institutions hosting a Central Facility of an ICOS Station, how would the project participation be distributed among them? How to balance between scientific excellence, feasibility, competence and even distribution of resources?

Core results from the survey related to Criterion 1

Externally funded projects are seen as very valuable by the Central Facilities and the Station PIs.

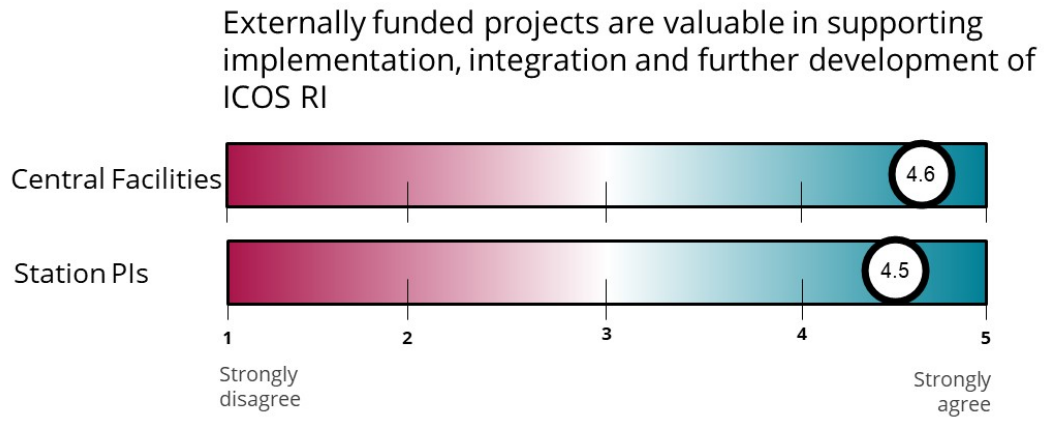


Figure 2.10: Externally funded project value.

The previous graphs in figure 2.8 have shown that project funding is well distributed within the research infrastructure. However, given the overall complexity, it is understandable that the survey statements about integration into planning, decision making and resource distribution of externally funded projects revealed low agreement particularly by the station PIs who do not feel well integrated in the project planning and decision making.

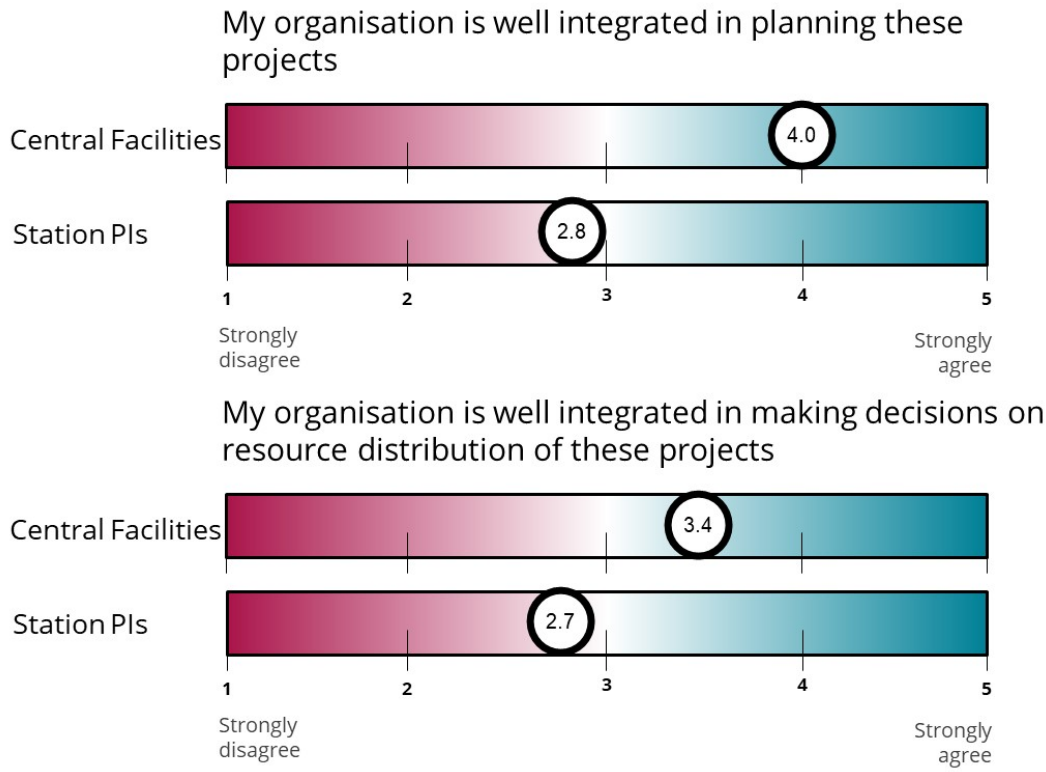


Figure 2.11: Survey results on integration into planning, decision making and resource distribution of externally funded projects.

Category 3: Internal Engagement and Integration (Structure)

3.1 Internal Engagement

Rationale

ICOS RI is a mosaic of communities with different geographical and focus-driven forms and operates on several scientifically differing domains. As ICOS RI consists of several types of organisations with different agendas and histories and spans different cultural, political and linguistic regions, 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 is 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: inclination and interest in participating in activities are signs of motivation.

Objective

An engaged RI

Criterion 1: People identify with the RI

- KPI 16: RI members identifying with ICOS
    - Indicators: Felt level of recognition, identification with, behaviours

Criterion 2: People are motivated

- KPI 17: Motivation of people involved in the ICOS RI operations
    - Indicators: Participation, interest

Evidence

Evidence for criterion 1: People identify with the RI

Table 3.1: Evidence material for subcategory 3.1 Internal engagement

Documents available in the Material folder	KPI
ICOS Identity Study	16, 17
ICOS Identity Study Results	16, 17

Survey questions related to subcategory 3.1, criterion 1	Target group
67./52./14. I usually attend the ICOS Science conferences.	Station PIs

68./53./15. I attend ICOS meetings of other domains than my own (atmosphere, ecosystems, ocean). 69./54./16. I contribute actively to the organisation of ICOS events. 70./55./17. I have participated in ICOS training events or meetings, such as MSAs and workshops. 71./56./18. I have collaborated with ICOS colleagues across domains (joint publications, projects, workshops etc). 72./57./19. Please provide examples of collaboration across domains.	CF Coordinators Focal Points

Evidence for criterion 2: People are motivated

Table 3.2: Evidence material for subcategory 3.1 Internal engagement

Documents available in the Material folder	KPI
ICOS Identity Study	16, 17
ICOS Identity Study Results	16, 17

Survey questions related to subcategory 3.1, criterion 2	Target group
65./50./12. I consider myself to be part of the ICOS Community. 66./51./13. My work is recognised as important in ICOS. 73./58./20. I promote ICOS in my social media channels. 74./59./21. I present ICOS-related work in non-ICOS conferences and workshops, mentioning ICOS. 75./60./22. When giving presentations outside of ICOS, I use the ICOS logo. 76./61./23. I visit the ICOS website regularly.	Station PIs CF Coordinators Focal Points

Results of the surveys

To evaluate how engaged and motivated ICOS RI is internally, the results are presented here aligned with the assigned KPIs and their indicators. The results from the quantitative questions in the surveys are presented first, followed by results from the qualitative (open ended) questions.

KPI 16: RI members identifying with ICOS

Indicators/criteria: Participation, interest

Quantitative data results

The survey results show that the RI members participate in across RI activities relatively actively, but participation in other domains' meetings is not widely practised (figure 3.1). Participation in the ICOS Science Conference was reported to be active in all respondent groups, but especially among Central Facility coordinators (84% report strong or somewhat strong participation) and the Focal Points (91% strongly or somewhat strongly participate). The PIs reported a 68% strong or somewhat strong participation (Note: the PI group was the largest of the respondent groups). In terms of participating in

meetings of domains' other than one's own, 27% of PIs; 24% of CF coordinators and 45% of FPs strongly or somewhat strongly reported doing so. When asked about contributing to the organisation of ICOS events, 72% of Focal Points, 40% of PIs and 76% of CF coordinators strongly or somewhat strongly agree on doing so. Participation in ICOS training events and meetings (e.g., MSAs and workshops, figure 3.2) was reported as strong or somewhat strong by 64% of the CF coordinators, 90% of PIs, and 64% of FPs. The question about having collaborated with ICOS colleagues across domains (e.g., joint publications, projects, or workshops) returned a 72% strong or somewhat strong agreement from the Focal Points, 58% from the PIs, and 60% from the CF coordinators.

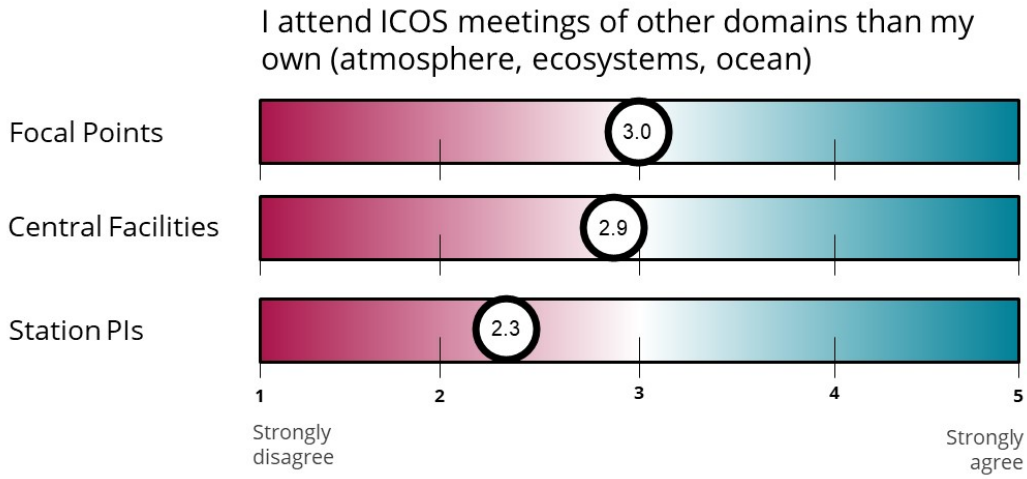


Figure 3.1: Attendance to ICOS meetings outside one's domain.

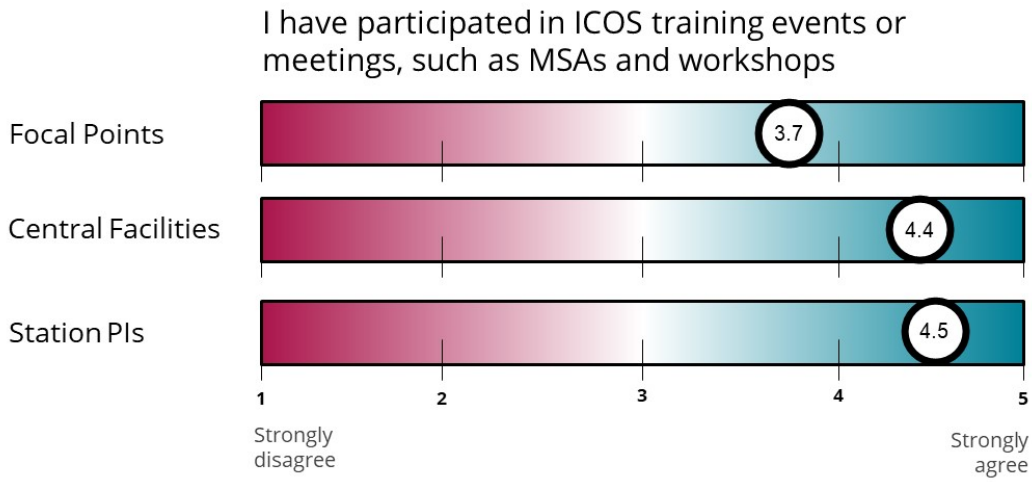


Figure 3.2: Attendance to training.

Indicators/criteria: behaviours, awareness

The survey results show that 30% of PIs, 44% of CF coordinators and 54% of FPs strongly or somewhat strongly agree that they promote ICOS on their social media channels (figure 3.3). 83% of PIs, 68% of CF coordinators and 100% of FPs strongly or somewhat strongly agree that they mention ICOS when presenting their ICOS-related work in non-ICOS conferences and workshops. Engaging with using the ICOS logo in presentations given outside ICOS was strongly or somewhat strongly agreed by 79% of PIs, 84% of CF coordinators, and 73% of FPs. When asked if respondents visited the ICOS website regularly, 48% of PIs, 64% of CF coordinators and 72% of FPs strongly or somewhat strongly agreed.

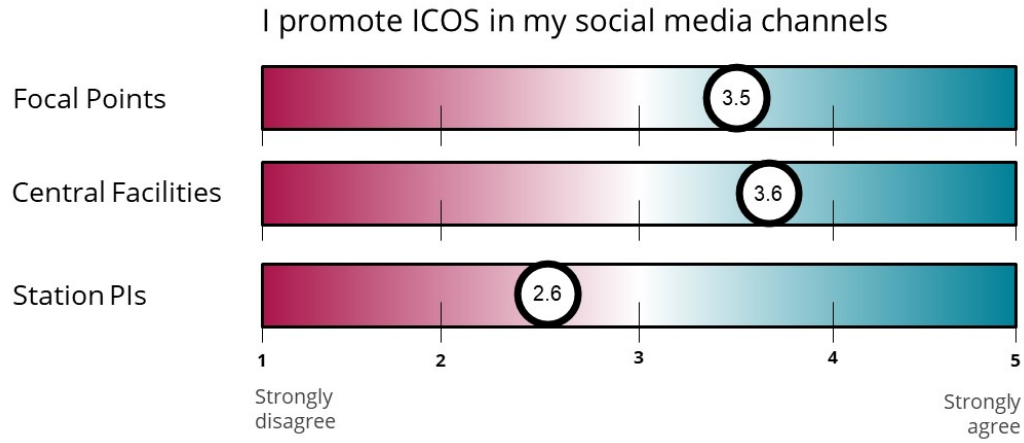


Figure 3.3: Promotion of ICOS through personal Social Media channels.

Summary: Members of the ICOS RI engage actively in the use of ICOS branding in their everyday work, but their reported behaviour in some respondent groups also suggests that engagement with promoting ICOS via social media and the information conveyed through the ICOS website could be further strengthened among the RI members.

Table 3.3: Comparison between ICOS Identity Study 2018 and Evaluation data 2020.

Comparison between ICOS Identity Study 2018 and Evaluation data 2020							**%**
Identity Study 2018	I consider myself to be part of the ICOS Community.						79
Evaluation data 2020 (all respondents combined)	I consider myself to be part of the ICOS Community.						82
Identity Study 2018	My work is recognised as important in ICOS.						67
Evaluation data 2020 (all respondents combined)	My work is recognised as important in ICOS.						75
Identity Study 2018	I am interested in developing community building (e.g., joint activities)						56
Evaluation data 2020 (all respondents combined)	I attend ICOS meetings of other domains than my own (atmosphere, ecosystems, ocean)	27	I usually attend the ICOS Science conferences	73	I actively contribute to the organisation of ICOS events	52	
Identity Study 2018	I am interested in undertaking training related to my scientific career						44
Evaluation data 2020 (all respondents combined)	I have participated in ICOS training events or in meetings such as (MSAs, workshops.)						75
Identity Study 2018	collaboration across all domains in ICOS should be increased						81
Evaluation data 2020 (all respondents combined)	I have collaborated with ICOS colleagues across domains (joint publications, projects, workshops etc). Please provide examples (open).						58
Identity Study 2018	ICOS is visible outside the scientific communities in my country						30
Evaluation data 2020 (all respondents combined)	I promote ICOS in my social media channels	35	When giving presentations outside of ICOS, I use the ICOS logo	77	I present ICOS-related work in non-ICOS conferences and workshops, mentioning ICOS.	77	

In the Identity Study 2018, the respondents reported a strong identification with the RI. This appears to have strengthened even further according to the Evaluation data 2020. They also increasingly feel that their work is being recognised as important in ICOS.

In the Identity Study 2018, respondents expressed a clear need, and a clear will, for more cross-domain community building and professional collaboration. According to the Evaluation 2020 data, participation in collaboration activities and in organising them appeared to be partly active (e.g., attendance to the ICOS Science Conferences, training and meetings), but it appeared to be more active within one's 'own' domain. Participation in cross-domain meetings and collaboration activities was less common – however, 58% of respondents reported having collaborated with other domains.

In the identity Study 2018, only 30% expressed that they think ICOS RI is visible in their country outside the scientific communities. The Evaluation 2020 data shows that in the scientific context, people are active in mentioning ICOS and utilising the tools to maintain its visual identity; but dissemination for the wider audience via social media was not so active. Comparing this set of questions, is not indicative of the whole situation about promoting ICOS for the non-scientific communities. It does, however, tell us that ICOS members are aware of the tools to promote ICOS and are building an organisational culture around utilising them inside the RI, which will, in the long term, also encourage them to promote the RI outside ICOS.

As understanding of the operating structure of ICOS had been challenging, it could have resulted in the perceived unclarity of mandates to one's tasks in ICOS and that it could contribute to decision-making on societal level.

Overall, it is believed that ICOS will have gained societal and scientific visibility, operability and geographical coverage in the next 3-5 years. The members are keen to develop both their own skills and the collaboration across domains, and most of the respondents see themselves still involved in ICOS in the near future.

When comparing the types of purposes, it is visible (figure 3.5) that those who perceive ICOS' main purpose to be scientific, regarded its main function as consisting of services to scientists and research, either via obtaining resources and providing a platform for conducting science or influencing science policy to obtain resources; whereas those who saw ICOS' main purpose to be societal, considered its main function as an influencer or path finder on multiple levels (policy, coverage and informative aspects).

Qualitative data results

The open questions about examples of the collaboration activities across domains show that there are several types of activities: Scientific/technical collaboration such as technical knowledge exchange, joint publications, workshops, meetings, external projects, PhD projects, collective research initiatives, researcher exchanges, and events.

Over 30% of the responses from the PIs mentioned collective research initiatives such as the Drought Study and the Winter Anomaly Study as examples of the collaboration activities; and call for more similar activities in the future: *"I would like to see more collaboration (the drought paper is a good example)"*. Over 25% of PIs mention joint publications. Slightly over 35% of CF coordinators mention external projects. Some FPs, however, also mention that there is no possibility to participate in cross domain collaborative activities due to lack of funding.

Summary: The survey results show that the RI members participate in cross RI activities relatively actively, but participation in other domains' meetings is not widely practised. There are several types of activities organised across domains, but not necessarily adequate resources for RI-wide participation.

KPI 17: Motivation of people involved in the ICOS RI operations

Indicators/criteria: Felt level of recognition, identification with

Quantitative data results

The survey results show a strong feeling of identifying with ICOS RI. 98% of PIs, 92% of CF coordinators and 100% of FPs report that they strongly or somewhat strongly consider themselves part of the ICOS community (figure 3.4). 90% of FPs, 84% of CF coordinators and 73% of PIs strongly or somewhat strongly feel that their work is recognised as important in ICOS (figure 3.5).

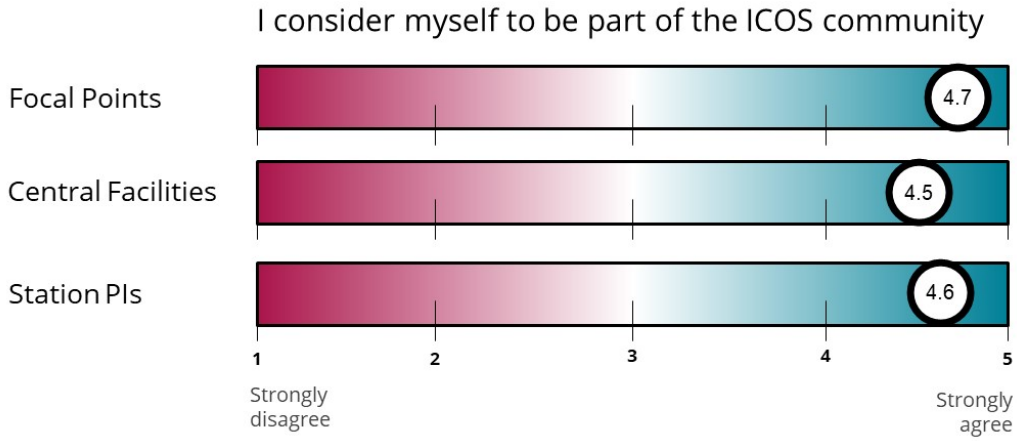


Figure 3.4: Felt belonging to the ICOS community.

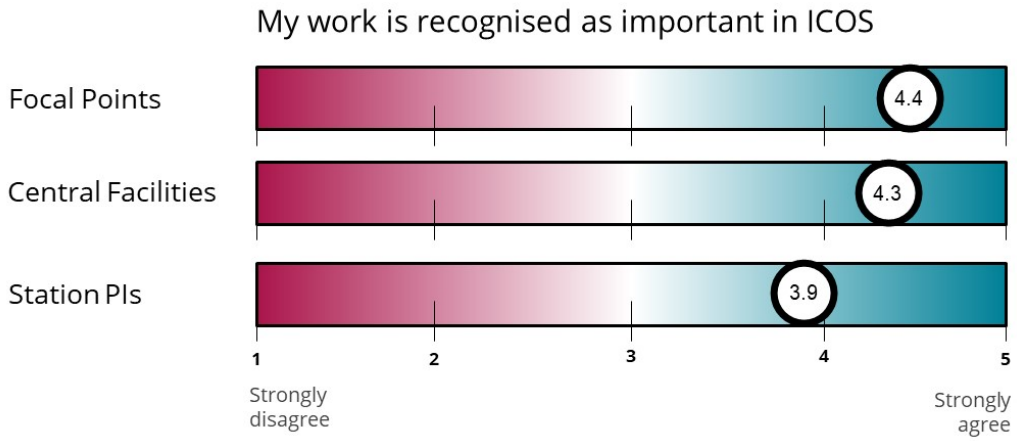


Figure 3.5: Felt importance of one's work in ICOS.

Summary: There is a strong sense of identifying with the RI and a high level of recognition felt.

3.2 Internal Integration and Structure

Rationale

'Integration', in the context of ICOS RI and this evaluation, refers to the RI's ability to include different parts of the RI in activities (meetings, events, documents, consultations, trainings, projects), the ability to improve activities and to respond in an agile way to new opportunities or challenges, and the potential for improving the RI's structure.

Objective

An integrated RI

Criterion 1: The organisational structure of ICOS RI is inclusive

(meetings, events, documents, consultations, trainings, projects)

- KPI 18: The inclusiveness of the organisational structure of ICOS RI
    - Indicators: Existing ways of including all parts of the RI, felt level of inclusiveness

Criterion 2: The organisational structure of ICOS RI enables the improvement of activities

- KPI 19: The ability of the organisational structure of ICOS RI to improve activities
    - Indicators: identified ways of possible improvements; felt level of the ability to improve activities

Criterion 3: The organisational structure of ICOS RI functions well in managing the RI

- KPI 20: The suitability of ICOS RI's organisational structure to manage the RI
    - Indicators: Felt quality of the organisational structure, felt need to alter the structure

Evidence

Evidence for Criterion 3: The organisational structure of ICOS RI is inclusive

(meetings, events, documents, consultations, trainings, projects)

Table 3.4: Evidence material for subcategory 3.2, criterion 1.

Documents available online	**KPI**
ICOS Handbook 2020	18

Documents available in the Material folder	**KPI**
Rules on project participation (Guidelines for participation in the projects-approved by GA.pdf)	18
Rules on cooperation (Cooperation rules)	18

Survey questions related to subcategory 3.2, criterion 1	**Target group**
77. ICOS is well integrated internally. 81. My MSA collaborates well with the other ICOS domains. 82. What kind of collaborative activities do you have in your MSA? What are the outcomes of these activities? Please provide examples!	Station PIs

62. ICOS is well integrated internally. 69. My Central Facility collaborates with other Central Facilities. 70. What kind of collaborative activities does your Central Facility have with the other Central Facilities? What are the outcomes? Please provide examples!	CF Coordinators
24. ICOS is well integrated internally.	Focal Points
31. ICOS is well integrated internally. 40. My MSA collaborates with other ICOS domains. 41. What kind of collaborative activities does your MSA have with the other domains? What are the outcomes? Please provide examples!	RI COM

Evidence for Criterion 2: The organisational structure of ICOS RI enables the improvement of activities

Table 3.5: Evidence material for subcategory 3.2, criterion 2

Documents available online	**KPI**
ICOS RI Annual Work Report 2017	19, 20
ICOS RI Annual Work Report 2018	19, 20
ICOS RI Annual Work Report 2019	19, 20
Progress report (2015-2017)	19, 20

Documents available in the Material folder	**KPI**
ICOS RI Annual Work Report 2016	19, 20
SAB Report 2016	19
SAB Report 2017	19
SAB Report 2018	19

Survey questions related to subcategory 3.2, criterion 2	**Target group**
78. How would you improve the internal integration in ICOS? 83. How would you improve the integration of the MSAs in ICOS activities?	Station PIs
63. How would you improve the internal integration of ICOS?	CF Coordinators
26. How would you improve the internal integration in ICOS?	Focal Points
32. How would you improve the internal integration of ICOS?	RI COM
36. The current structure of ICOS RI is the most functional one. There is no need for structural changes.	General Assembly

Evidence for Criterion 3 The organisational structure of ICOS RI functions well in managing the RI

Table 3.6: Evidence material for subcategory 3.2, criterion 3

Documents available online	KPI
ICOS RI Annual Work Report 2017	19, 20
ICOS RI Annual Work Report 2018	19, 20
ICOS RI Annual Work Report 2019	19, 20
Progress report (2015-2017)	19, 20

Documents available in the Material folder	KPI
ICOS RI Annual Work Report 2016	19, 20
SAB Report 2016	19
SAB Report 2017	19
SAB Report 2018	19

Survey questions related to subcategory 3.2, criterion 2	Target group
79./64./33./36. The current structure of ICOS RI is the most functional one. There is no need for structural changes. 80./65./34./37. What kind of structural changes would you suggest and why would they improve the efficiency of ICOS RI?	Station PIs CF Coordinators RI COM General Assembly

Results of the surveys

KPI 18: The inclusiveness of the organisational structure of ICOS RI

Indicators: felt level of inclusiveness

Quantitative data results

The survey results show that 48% of PIs, 24% of CF coordinators, 54% of FPs, 56% of RICOM; and 53% of GA report that they strongly or somewhat strongly agree with ICOS RI being well integrated internally. 25% of RICOM strongly or somewhat strongly agree that their MSA is well integrated in ICOS activities, while 64% of CF coordinators strongly or somewhat strongly agree that their CF is well integrated in ICOS activities. 91% of FPs strongly or somewhat strongly agree that their National Network community is well integrated in ICOS activities, and 92% of GA indicates that they are strongly or somewhat strongly connected to their national ICOS communities.

37% of PIs strongly or somewhat strongly agree that their MSA collaborates well with other ICOS domains, while 56% of CF coordinators strongly or somewhat strongly agree that their CF collaborates with other CFs.

When asked if all Thematic Centres and CALs contributed to ICOS tasks equally well, 32% of CF coordinators strongly or somewhat strongly agreed. 100% of HoUs somewhat disagreed or neither agreed nor disagreed that the different domains participated in projects in a common and equal way (figure 3.6), and 100% somewhat disagree or neither agree nor disagree with the different domains participating in projects in an adequate way. When asked their opinion on project work being always shared between the domains, 25% strongly or somewhat strongly agreed, and 75% somewhat disagreed or neither agreed nor disagreed. 75% of HoUs strongly or somewhat strongly agreed that the different domains contributed to internal tasks (e.g., preparing documentations/deliverables, organising events etc.).

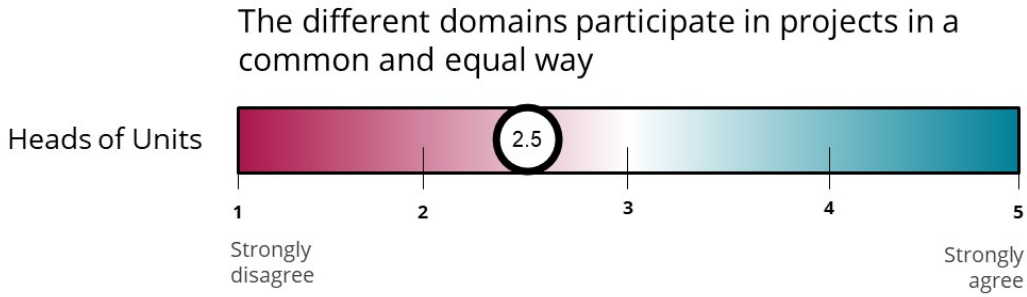


Figure 3.6: Different domains' participation in projects in a common and equal way.

Summary: The survey results indicate that the level of inclusion is not perceived very strongly especially related to the MSAs. Similarly, the level of how the different domains collaborate with each other is not very strongly felt in the MSAs and CFs. The FPs and GA, however, indicate strong feelings of inclusiveness – it could be reflected on whether having a membership in a coordinating/decision-making body contributes to this feeling. Project participation also received a generally low level of inclusiveness.

KPI 19: The ability of the organisational structure of ICOS RI to improve activities

Indicators: Felt level of the ability to improve activities

Quantitative data results

54% of FPs strongly or somewhat strongly agree that there is potential to improve the integration in ICOS, and 26% of RICOM strongly or somewhat strongly agree that there is potential to improve the integration of the MSAs' in ICOS activities (figure 3.7).

82% of FPs strongly or somewhat strongly agree that the Head Office collects feedback from them and improves internal organisation of ICOS RI accordingly, while 19% of RICOM strongly or somewhat strongly agree that the Head Office collects feedback from their MSA and improves ICOS' internal organisation accordingly.

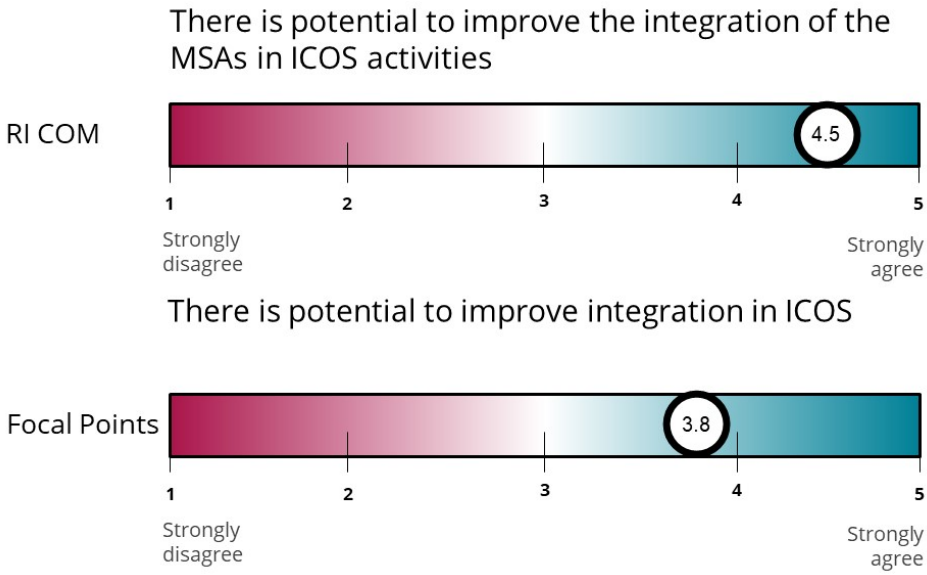


Figure 3.7: Potential to improve the integration of the MSAs in ICOS activities.

26% of RICOM strongly or somewhat strongly agree that the Head Office supports their MSA sufficiently, while 81% of FPs strongly or somewhat strongly agree that the Head Office supports them as the Focal Point and their National Network sufficiently.

50% of the HoUs strongly or somewhat strongly agree that organising events in ICOS has improved over the last five years, and 50% also strongly or somewhat strongly agree that managing projects has improved over the last five years.

The CP indicated they neither agreed nor disagreed about receiving sufficient support from all ICOS domains. Some limitations in technical capacities of the TCs was recognised as problematic in this. In terms of support from the HO, CP reported receiving it somewhat sufficiently, but felt that the HO is not collecting a lot of feedback from the CP to improve internal organisation. The CP reported there being a strong ability to improve their integration into the RI's activities. CP felt, however, that the operationality is sometimes complicated by the elaborate management processes.

Qualitative data results

The open questions asked how respondents would improve the internal integration of ICOS RI and the integration of the MSAs into ICOS activities. The HoUs were also asked their views on improving work flows between the HO and RI.

The data about improving internal integration (figure 3.8) brought out several different themes related to coordination of community building activities. The GA especially highlighted that they support the development of the ICOS Engagement Plan, as has been in the process: *"We would support the development of an ICOS RI engagement plan that aims at fostering synergies and increasing the sense of community between the different components of the RI".* PIs also suggested showing the community efforts more: *"Showing internally (and to the external audience and data users) how atmospheric, ecosystem and ocean parts fit together. "*

Improving information flows on important calls and decisions was a theme that received multiple comments. For example, some RICOM respondents reported that "*some PIs complain about a too limited sharing of information, especially about project preparation/participation. We should find a way to make this flow of information more efficient. Can the chairs more systematically inform MSAs about outcomings of RI-COM meeting?*". FPs also called for "*timely announcements of proposal calls and providing possibility to participate*" and suggested having a list of all ICOS members; and PIs suggested "*improving the involvement of station PIs in the preparation of proposal to be submitted to funding agencies*".

All respondent groups suggested increasing collaboration and sharing information across domains. PIs suggested including *"ATM measurements at ETC sites*"; "*Common papers that cover all three systems*", and also more interaction between the CFs, training and concrete station visits. FPs suggested whole RI-wide annual meetings, and RICOM suggested increasing the number of joint scientific efforts, such as the Drought Study.

Increasing the number of common projects was also suggested, as well as securing funding to enable collaboration and integration, and clarifying instructions. Simplifying the organisational structure and avoiding repetition was also mentioned, as a PI indicated: *"quite often ETC are measuring the same things as ATC but have completely different instrument requirements (that quite often are inferior or don't work as well)".* Some respondents also felt that there was no need to improve.

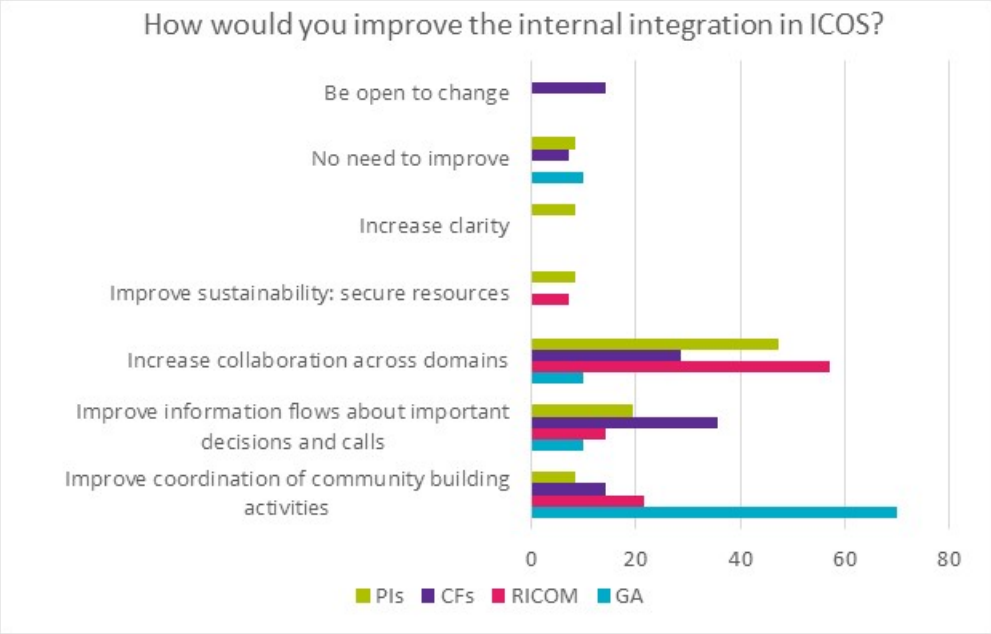


Figure 3.8: Suggested ways to improve the internal integration in ICOS.

The responses about how to improve the integration of the MSAs into ICOS activities (figures 3.9 and 3.10) indicated that the CF coordinators would increase organisational clarity, improve information flows on important calls and decisions, increase PIs' decision-making power, and introduce more interaction between the domains. The PIs mentioned securing resources, more interaction between domains, more joint scientific and technical activities, improved cross-domain activities, improved internal communication and organisation, and improving access to activities.

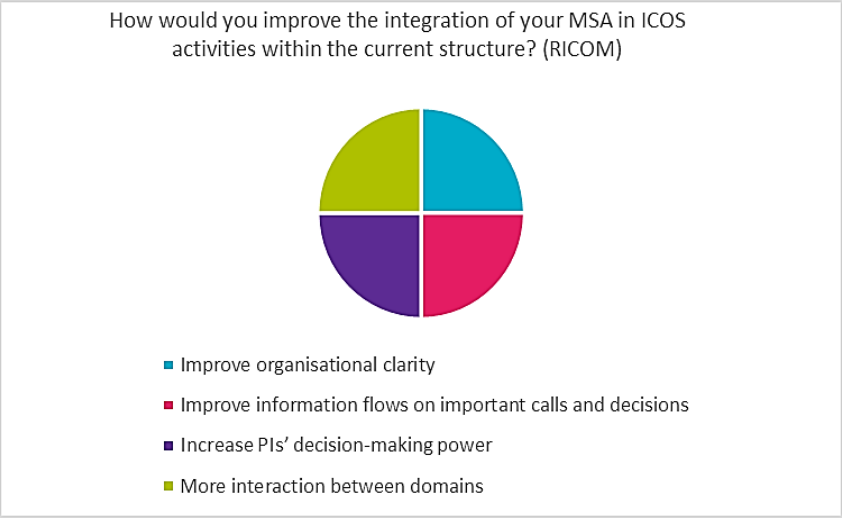


Figure 3.9: Suggested ways to improve the integration of MSAs in ICOS activities within the current structure of the RI (RICOM).

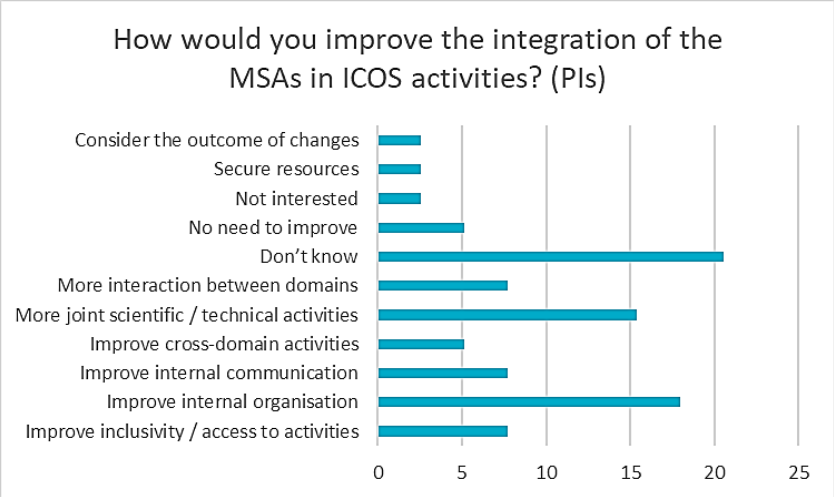


Figure 3.10: Suggested ways to improve the integration of MSAs in ICOS activities within the current structure of the RI (PIs).

For the view on improvements in work flows between the HO and RI, the HoUs reported that the general organisation of events and managing projects has improved in recent years, mainly due to better information flows, priority clarification, and task distribution. However, they also indicated that there is room for improvement in these areas. Feedback mechanisms currently in use between the HO and RI components include regular meetings and asking for comments on various types of documents, but the latter was not perceived to be very effective. In terms of organising the work in the HO based on feedback from HO staff, the HoUs reported implementing clarified task descriptions and information chains, and discussing processes and outcomes within their units.

Summary: There are differences between the felt level of ICOS RI's ability to improve its activities. The FPs generally feel that ICOS RI is capable of improving its activities, while the RICOM is less convinced. The HoUs indicate they feel an improvement in event organising and project management. The FPs feel supported by the HO, while the RICOM expresses receiving a lower level of support from the HO related to their MSAs. For increased inclusivity, coordinated community building efforts, improved information flows about important decisions and calls, increasing scientific and technical collaboration, common projects, securing resources, increasing PIs' decision-making power, improving access to activities, improving internal organisation and communication, and clarifying instructions were suggested. The HoUs reported a generally improved ability to organise events and manage projects, but also indicated there still room for improvement.

KPI 20: The suitability of ICOS RI's organisational structure to manage the RI

Indicators: Felt quality of the organisational structure, felt need to alter the structure

When asked what the respondents felt about the current structure of the RI not needing change (figure 3.11), 53% of PIs, 12% of CF coordinators, 47% of RICOM; and 62% of GA strongly or somewhat strongly agreed.

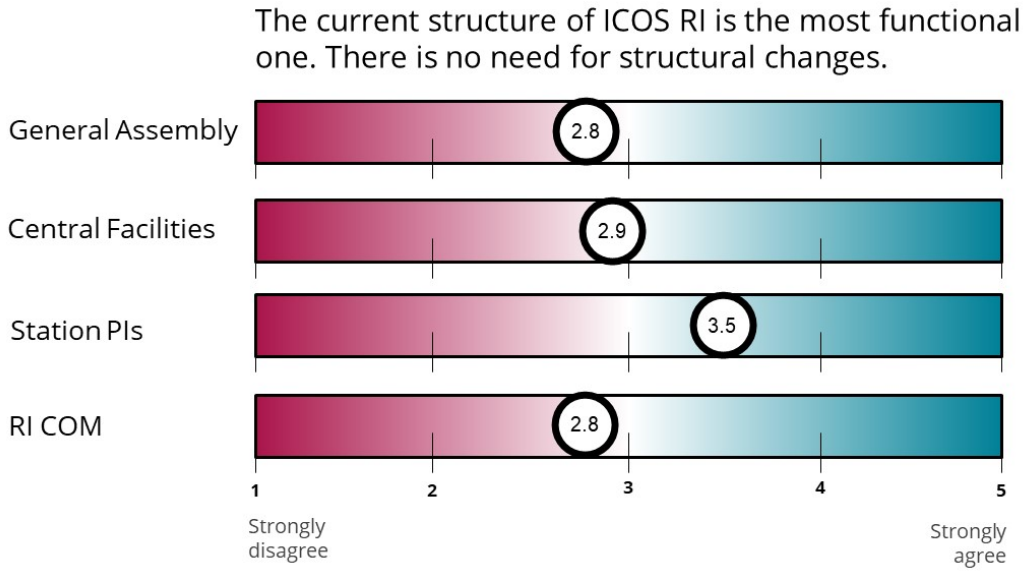


Figure 3.11: Felt functionality of the structure of ICOS RI.

Qualitative data results

The open question asked what kind of structural changes they would suggest to improve the efficiency of ICOS RI.

The types of structural changes suggested to improve the efficiency of ICOS RI (figure 3.12) included changing decision-making processes by re-distributing decision-making power within and between the different groups *("I think the ICOS management does not account for the distributed nature of the ICOS-RI among HO, CP, CFs and station networks and that relevant decision making should be delegated to the respective TCs, CFs and MSAs"; "MSA should have a stronger influence in ETC operation"; "PIs and operators do also have limited authorisation"*) and increasing clarity (especially PIs and CF coordinators mentioned this). Increased interactions and organisational changes were mentioned especially by CF coordinators, though several other respondents also highlighted there is no need to change the structure.

For the organisational changes (figure 3.13, the respondents suggested additional central facilities or support structures (e.g. "*Create a central facility for calibration of ETC that manage spare sensors" and "create a task force that helps labelling for ETC*"), more equal structure *("The current structure is a top-down structure where the national networks are not recognised very visibly"*), including the CFs into ERIC, mentioned especially by the GA *("We would support a change in the governance towards a structure where all the CF are part of the ERIC"*), and simplifying the organisational structure *("Very difficult to navigate in the structure of the ICOS"*).

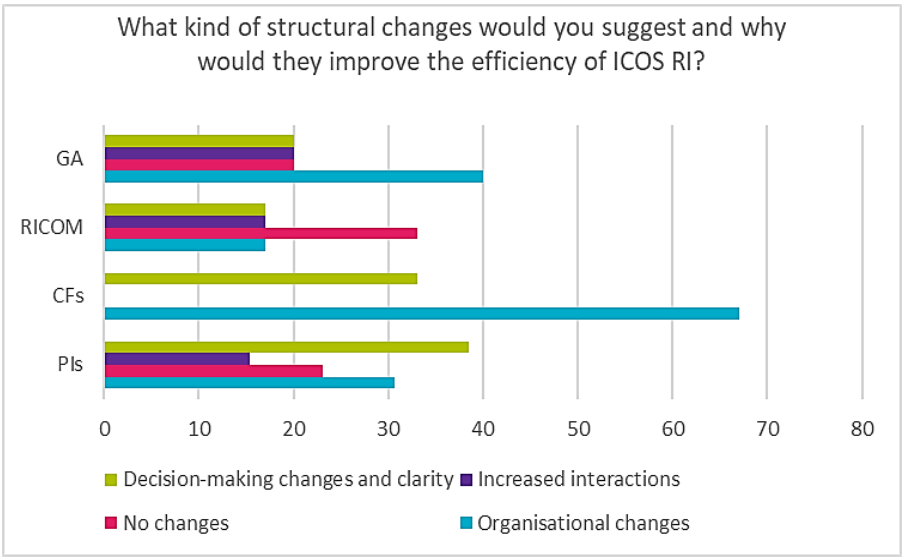


Figure 3.12: Suggested structural changes to improve the efficiency of ICOS RI.

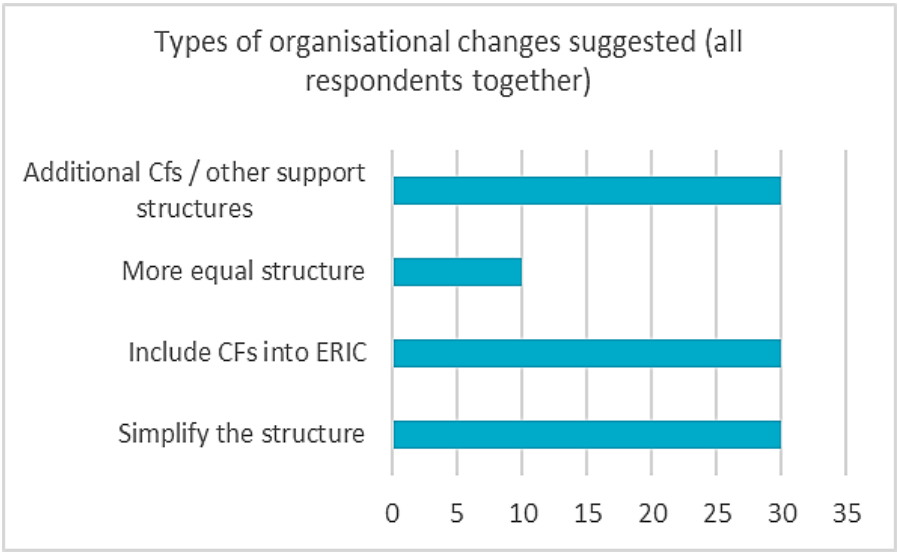


Figure 3.13: Suggested organisational changes.

Summary: The need to change the structure of ICOS RI felt by the different respondent groups varied, with CF Coordinators feeling most strongly that changes are needed. Almost half of other groups and over 60% of GA also felt so. Most suggestions were related to organisational changes like adding support structures, making the organisational structure more equal, including CFs into the ERIC, and simplifying the structure. Other suggestions were related to changing the decision-making by re-distributing decision-making power and adding clarity to the organisation. Respondents also called for increased interaction.

Category 4: ICOS Data and User Expectations

4.1 A Priori Design

Rationale

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.

Objective

The main objective of network design is a well-designed observational network that reflects user needs and international standards.

The question to ask: How well is the network designed and how well does it reflect the user needs and international standards?

Criterion

ICOS participates or enables participation in international efforts to co-design standards for ICOS measurements.

KPIs for Criterion 1:

KPI 21: ICOS-related participation in international efforts to co-design standards for ICOS measurements.

Evidence

Table 4.1: Evidence material for subsection 4.1

Documents available online	KPI
ICOS Handbook 2020	21
GCOS home page	21
GCOS Implementation Plan 2016	21
ICOS data use statistics	22
ICOS in scientific publications	24
The second report on the adequacy of the global observing system for climate in support of the UNFCCC GCOS-82	21
Final report of the GEMS project GEMS	21
Monitoring Atmospheric Composition and Climate MACC	21
Monitoring Atmospheric Composition and Climate Interim Implementation MACC-II	21
Monitoring Atmospheric Composition and Climate -III MACC-III	21
Operational Global Carbon Observing System GEOCARBON	21

World Data Centre for Greenhouse Gases (WDCGG)	21
Surface Ocean Carbon Atlas (SOCAT)	21
The data portal serving the Fluxnet community FLUXNET	21
Publications about SOCAT	21
Products based on SOCAT data products	21

GCOS invented the 'Essential Climate Variables' (ECVs) *'that are required to support the work of the Convention* [UNFCCC] *and that are technically and economically feasible for systematic observation*' (GCOS-82, 2003). ICOS has been developed by a community of scientists and institutions actively involved in the introduction as well as the continuous update of the GCOS system of ECVs, and the ocean counterpart - the 'Essential Ocean Variables' (EOV) by Global Ocean Observing System (GOOS). During the design, key persons within ICOS had been in the different GCOS panels or working groups of the Group on Earth observation (GEO).

The process has been well supported by a long series of EU projects. Since these projects also actively participated in GAW, GCOS and GEO, they bridged the ICOS, European and global coordination efforts and enabled a co-design with European and global requirements.

From its beginning, ICOS observations were shaped by international cooperation with respective networks, research infrastructures or agencies, either by direct cooperation or through global data compilation and standardisation efforts by, namely, the World Data Centre for Greenhouse Gases (WDCGG), Surface Ocean Carbon Atlas (SOCAT), and FLUXNET.

4.2 Data Download

Rationale

Amount of ICOS data downloaded via Carbon Portal or other routes is a key success parameter for the attractiveness of ICOS.

Objective

The main objective is that ICOS data is downloaded and cited extensively.

The question to ask: How extensively is ICOS data downloaded and cited?

Criteria 1 – 2

1. ICOS data is downloaded from the Carbon Portal by users in all ICOS domains.
2. ICOS data is downloaded via other portals (e.g., FLUXNET, SOCAT, ObsPack, etc.)

KPIs for Criterion 1 and 2:

KPI 22: Amount of ICOS data downloads

Evidence

Table 4.2: Evidence material for subsection 4.2

Documents available online	KPI

ICOS data use statistics	22

Documents in Materials folder	KPI
Sum of times cited per year	22

Survey questions related to criterion 1	Target group
1. I know what Integrated Carbon Observation System, ICOS is. 2. For your research, where did you download the data from? The ICOS Carbon Portal A community repository such as FLUXNET, SOCAT or ObsPack Another source (please specify in the box below) 3. Please specify the data source if you selected 'other' from the drop-down menu above 4. The data were easy to find. 5. The data were easy to access. 6. The ICOS data are timely. 7. The data are of high quality. 8. The instructions to cite the data are clear. 10. Did you contact the data providers to receive additional information? Yes, I contacted the data provider(s) No, because I did not know how to contact the data provider(s) No, I did not contact the data provider(s) 10. In case you contacted the data provider(s): The data provider was able to provide support. 11. The ancillary data were valuable 12. The metadata were valuable 13. Please, give us your suggestions on how to improve the data provision? 14. Do you have any other comments?	Scientific users

Carbon Portal saves extensive information on data downloads which can be used for a number of statistics. Data download statistics from ICOS Carbon Portal are calculated per theme (Atmosphere, Ecosystem, Ocean), per level, per parameter and per month. Examples of download counts for the most important ICOS and elaborated data products are shown in figures 4.1- 4.4.

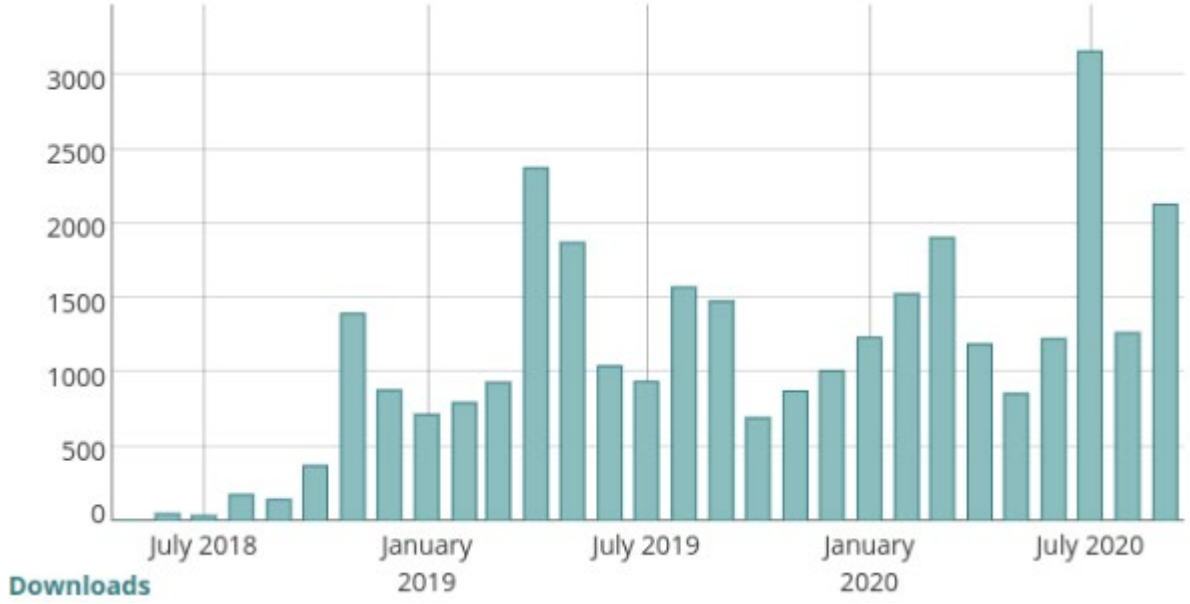


Figure 4.1: ICOS Atmosphere Level 2 CO_2 data product monthly downloads until Oct 2020.

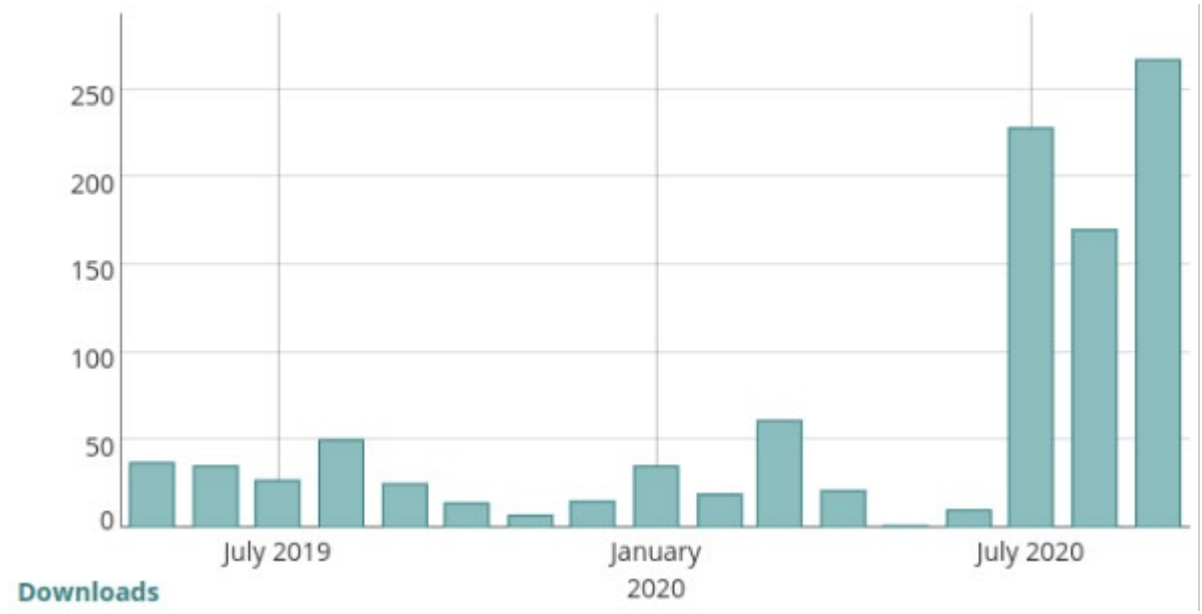


Figure 4.2: ICOS Ecosystem Level 2 monthly downloads until Oct 2020.

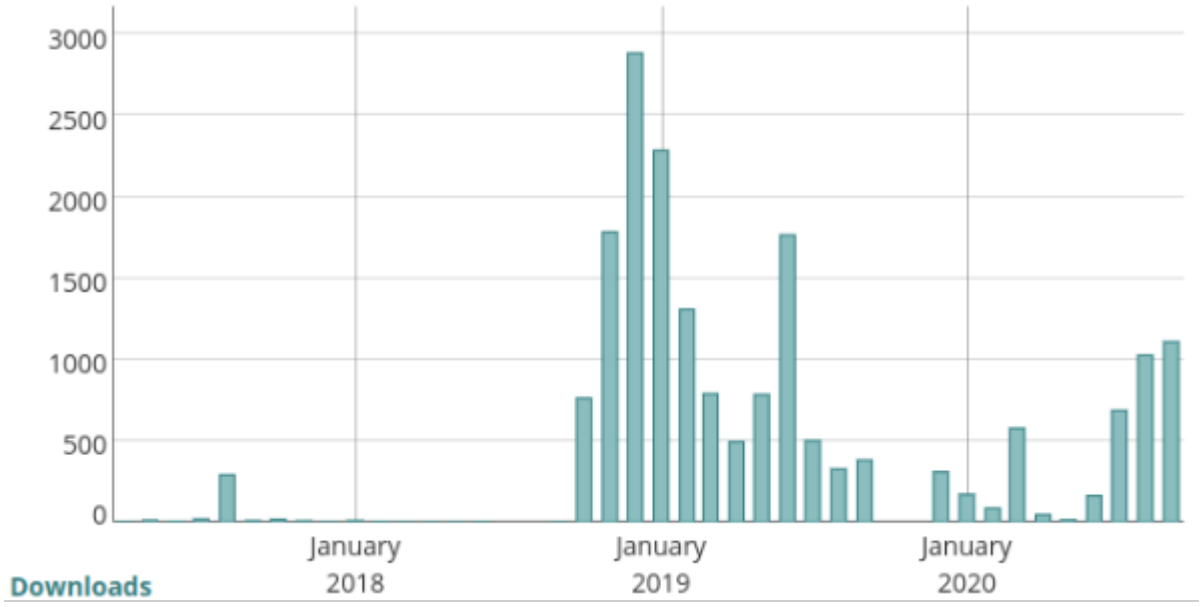


Figure 4.3: ICOS Ocean Level 2 monthly downloads until Oct 2020.

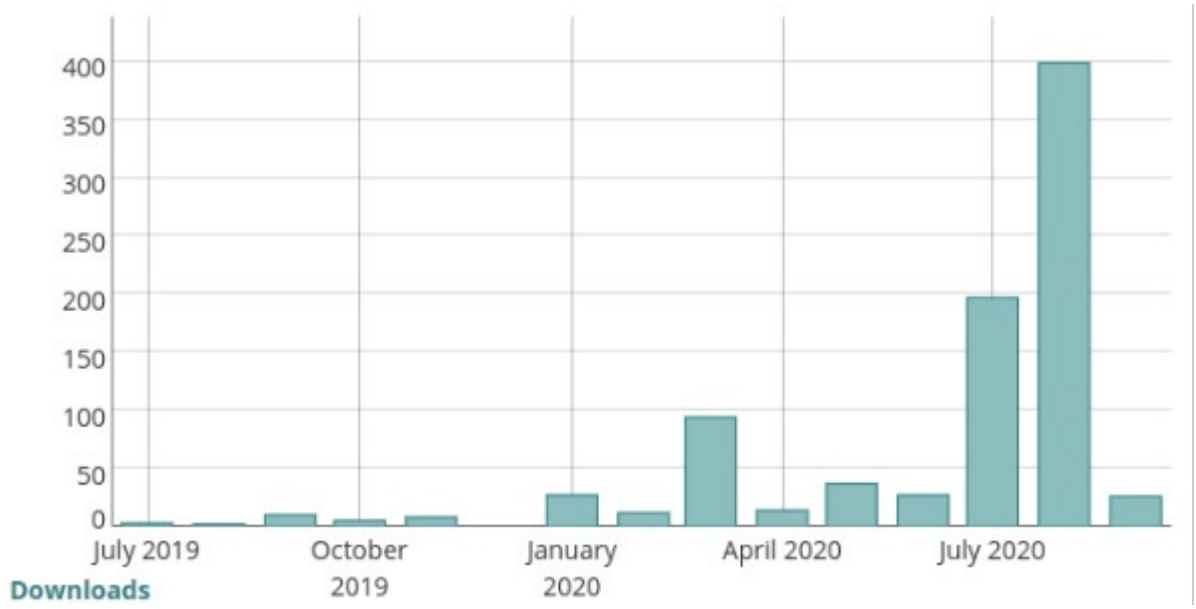


Figure 4.4: All ICOS Atmosphere Near Real Time data products monthly downloads until Oct 2020.

Amount of ICOS data used by scientists is not unambiguous to log, as a lot of data is available as part of global data sets in other portals. ICOS is working to track its datasets via these routes too, by promoting use of PID and DOI.

(pre-)ICOS data is also downloaded from other portals as part of global datasets. Most ICOS Atmosphere station data are distributed through WDCGG and as part of the NOAA/ICOS ObsPack Globalview data products. Ecosystem data are shared via FLUXNET and ICOS Ocean data is part of the SOCAT data.

Core results from the survey related to Criterion 1

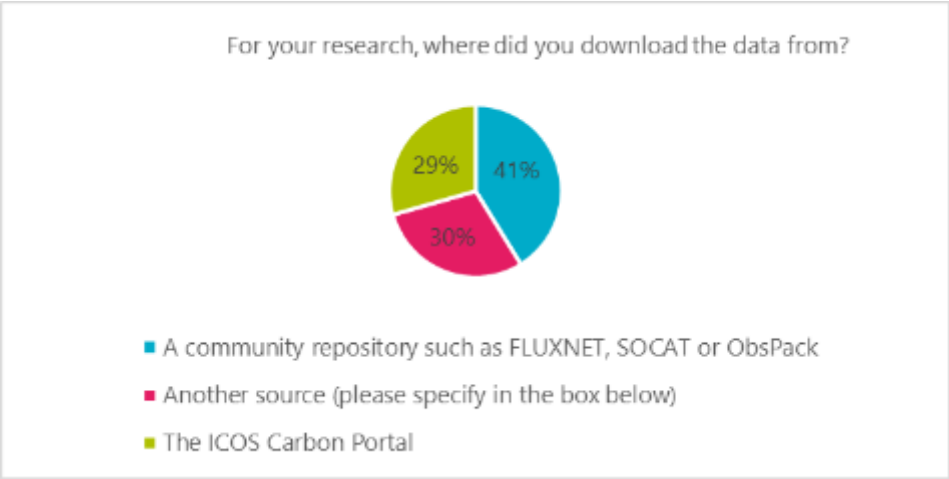


Figure 4.5: A core result related to survey about Data download.

In the Survey, questions about data download were asked to the Scientific users. Even though roughly 2/3 had downloaded the data from a third-party data portal, the average knowledge of what ICOS is, was generally good (average score 4.6 out of 5).

4.3 ICOS Data Usage

Rationale

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.

Objective

The objective is extensive usage of ICOS data.

The question to ask: How extensively is ICOS data used and does the usage reflect its scientific value?

Criterion 1: ICOS data is used and cited in scientific publications

KPIs for Criterion 1:

KPI 23: Usage of ICOS data in publications and number of citations of publications using ICOS data.

Criterion 2: ICOS data is used across different scientific fields

KPIs for Criterion 2:

KPI 24: Research areas where ICOS data are used.

KPI 25: Application of ICOS data in (globally leading) models.

KPI 26: Use of ICOS data towards support of satellite observations.

Criterion 3: ICOS data is used in education

KPIs for Criterion 3:

KPI 27: Usage of ICOS data in educational tools and activities.

Evidence for Criterion 1: ICOS data is used and cited in scientific publications

Table 4.3: Evidence material for subsection 4.3

Documents available online	KPI
ICOS in scientific publications	24
SOCAT publications	

Documents in Materials folder	KPI
Figures Bibliometric September 2020 Number of citations	24
Figures Bibliometric September 2020 Number of publications	24
ICOS bibliometric report September 2020	24

Number of ICOS-related publications

ICOS Carbon Portal manages an online database containing references to ICOS-related scientific publications. The objective of this database is to collect information about all the publications fulfilling one or both of the following criteria:

- **ICOS or pre-ICOS data are used in the publication.** All data since 2010 from any ICOS nominated station is here considered as "ICOS or pre-ICOS data". The rationale behind this definition is that the national funding for ICOS supporting the station networks started in 2010. Even though this rationale may not apply to all stations, no separation was done between different stations.
- **ICOS funds have been used to support the writing of the publication.** This can happen if the author's salary has been (at least partly) paid by any ICOS funds (e.g., national grant for ICOS or, since 2016, ICOS host country contributions or Member contributions) or they have participated in an ICOS-related EU project.

The standard methods for collecting new references in the Carbon Portal publication database have previously included:

- National Focal Points provide a list of publications in their annual report
- Central Facilities personnel add publications they are aware of

ICOS data can be accessed through Carbon Portal, but is also available through datasets such as FLUXNET and SOCAT, and the use of the data is not always directly indicated in the publication. Therefore, an extensive search through various databases was needed to find the publications missing from the Carbon Portal database. The search was conducted by a team in the Head Office during August 2020. The database in Carbon Portal included 870 references to ICOS-related publications when the search started.

The extensive search for unlisted ICOS-related publications resulted in the addition of 534 new publications to the Carbon Portal database. Thus, the total number of ICOS-related publications in the Carbon Portal database reached 1404. This number also includes the newest publications from 2020.

The total number of ICOS-related publications (until the end of 2019) is 1273. The number of publications by year is shown in figure 4.6.

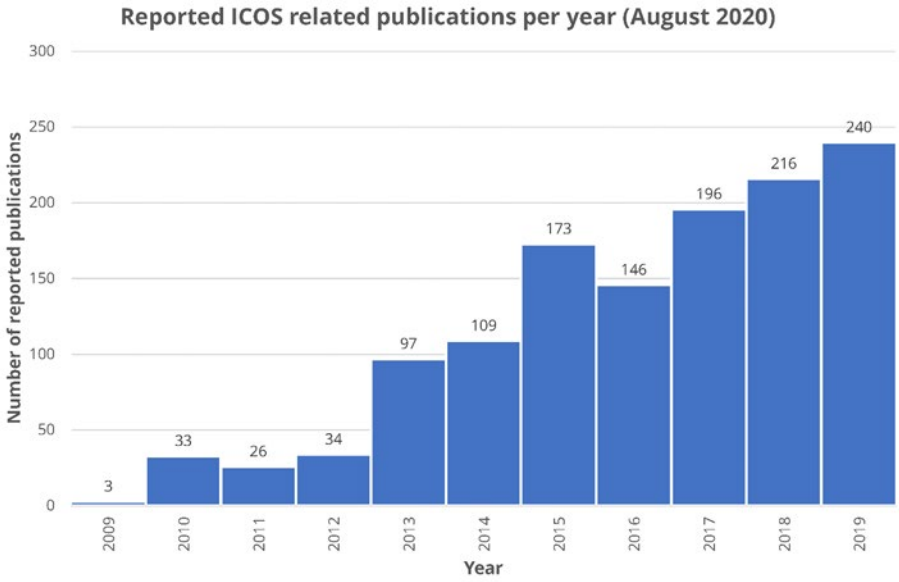


Figure 4.6: ICOS related publications.

Citations of ICOS-related publications

The number of citations (how many other scientific publications have cited ICOS-related publications in their reference list) of reported ICOS-related publications is 27 251. The number of citations per year (as of August 2020) is shown in figure 4.7:

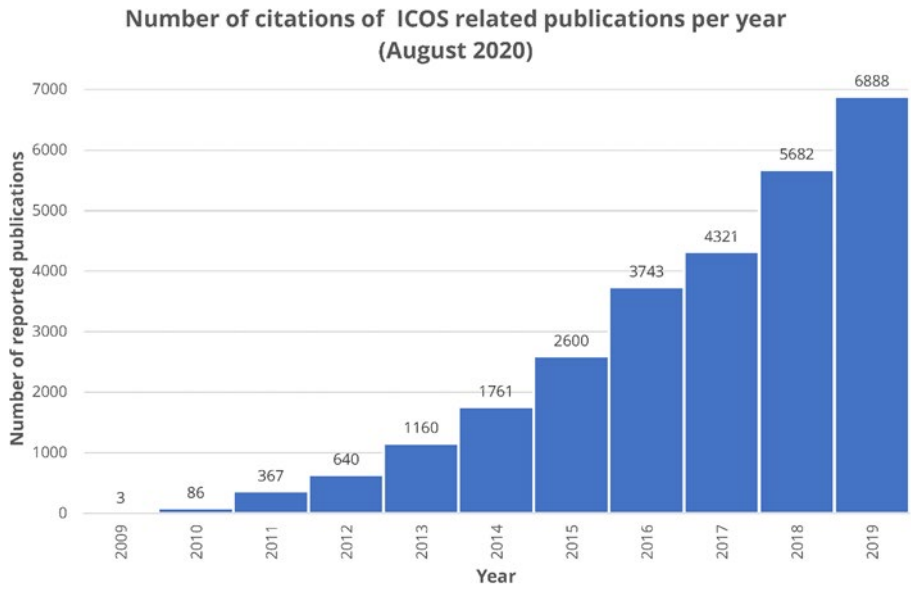


Figure 4.7: Number of citations.

Core results from the survey related to Criterion 1

The ICOS survey was sent to a group of Scientific users who were first authors of the journal papers, where ICOS data had been used. Some of them took the data directly from Carbon Portal, while others via third party portals (see section 4.2). On average, the scientific users were of the opinion that ICOS data is of high quality, and many of them knew what ICOS is.

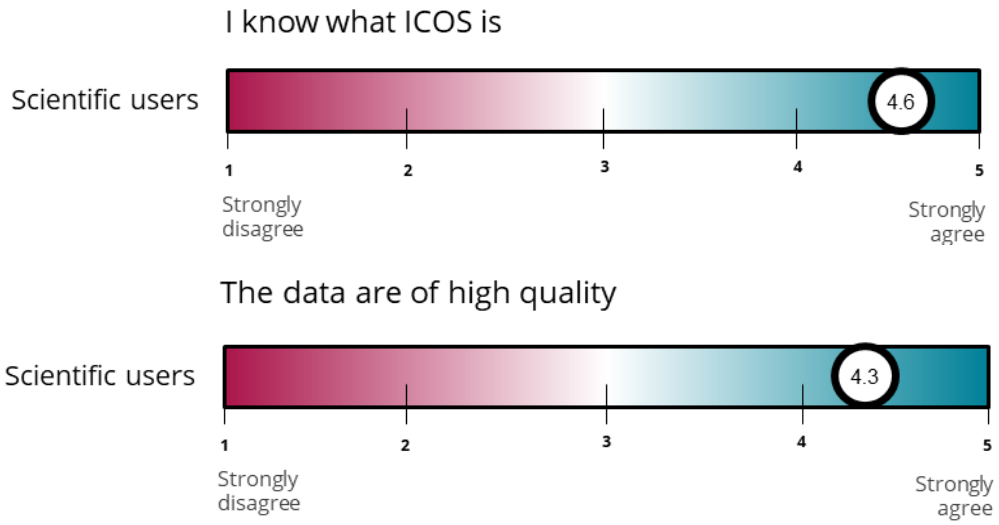


Figure 4.8: Survey results among Scientific users about whether they know what ICOS is (upper heat bar) and if they thought that ICOS data are of high quality.

Evidence for Criterion 2: ICOS data is used across different scientific fields

Table 4.4: Evidence material for subsection 4.3

Documents in Materials folder related to criterion 2	KPI
U&S Map for evaluation	23
Article categories (bibliometry)	23
Evaluation subject categories	23
Number of publications per impact factor group	23

Survey questions related to criterion 2	Target group
Think about your role as a scientist using ICOS data: 88a /76a. ICOS data is Very important in my personal field of science. 88b/76b. ICOS data is Easy to access. 88c/76c. ICOS data is Comprehensive in terms of metadata and ancillary data.	Station PIs CF coordinators

Research areas where ICOS data are used

The articles using ICOS data were sorted into categories according to Web of Science, the global citation database by Clarivate. There were articles in 58 categories: the largest being Meteorology and

Atmospheric sciences (424 papers, 37% of all), followed by Environmental sciences (380 papers, 34%). The 20 most common categories are presented in the tree map below (figure 4.9).

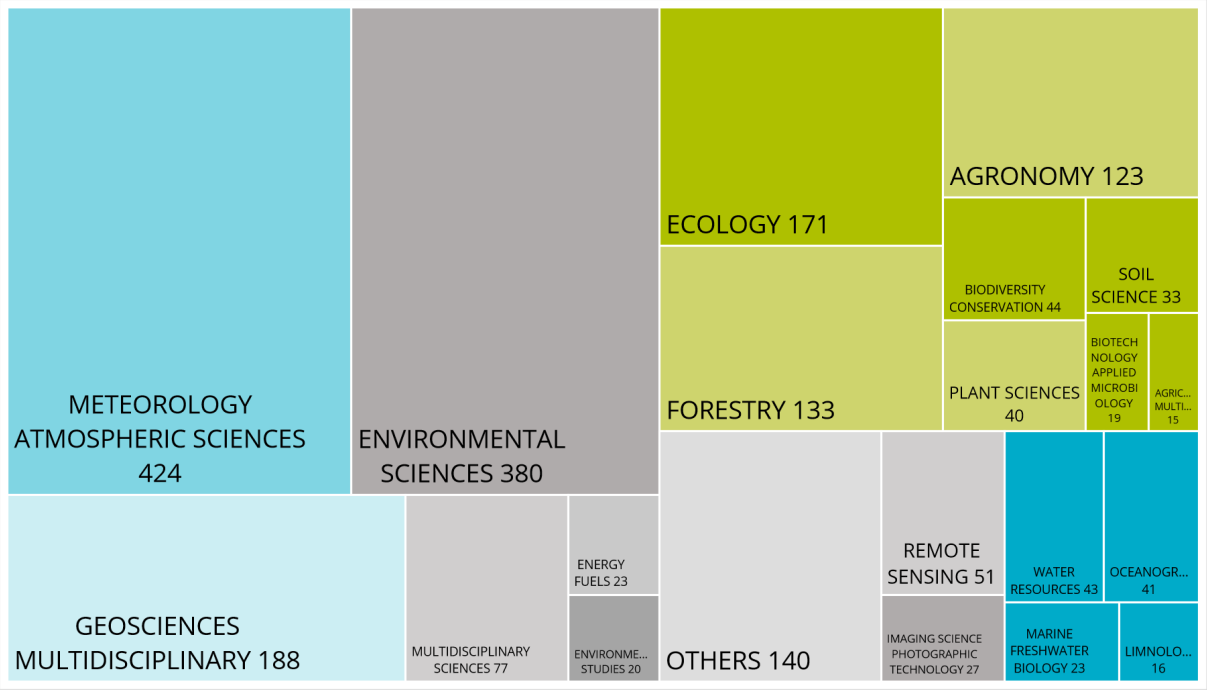


Figure 4.9: Scientific categories and number of publications in each category that have used ICOS data.

Application of ICOS data in (globally leading) models

The ICOS network as a high density, in situ surface observation network enables, in theory, inversion modelling at a resolution close to the country scale. This has led to the development of many regional inversion systems capable of assimilating this high-resolution data. In the EUROCOM Project, ICOS Atmospheric data was used by six different groups, with six inversion systems:

- PYVAR-CHIMERE (Broquet et al., 2011; Fortems-Cheiney et al., 2019) developed at LSCE, France.
- LUMIA (Lund University Modular Inversion Algorithm, Monteil and Scholze, 2019), developed as part of the EUROCOM project at Lund University, Sweden.
- CarboScope-Regional (Kountouris et al., 2018a, b) developed at MPI-Jena, Germany.
- FLEXINVERT+ (Thompson and Stohl, 2014) from NILU, Norway.
- NAME-HB (White et al., 2019) from University of Bristol, United Kingdom.
- CarbonTracker Europe (Peters et al., 2010; van der Laan-Luijkx et al.2017), from the University of Wageningen, the Netherlands.

In the TRENDY experiment (Trends in net land-atmosphere carbon exchange over the period 1980-2010), a set of most used Dynamic Vegetation models generates maps of ecosystem net exchange fluxes. All these models use ICOS observations to calibrate and validate their parametrisations. The outcome of TRENDY is directly used in the GCP yearly analysis of the global carbon cycle. The same models also provide prior information to the aforementioned inversion systems. The participating models in TRENDY are Hyland, JULES, LPJ, LPJ-GUESS, NCAR-CLM4, ORCHIDEE, OCN, SDVGM and VEGAS (see below for details).

The value of ICOS data is not limited to direct assimilation, for e.g., COPERNICUS data on CO_2 fossil fuel fluxes has been optimised using ICOS CO_2 NRT observations (Agusti-Panareda et al., 2019). All

atmospheric inversions from, for example, the TRANSCOM community and the COPERNICUS CAMS services rely on the prior estimates of NEE, which are based on Dynamic Global Vegetation Models (DGVM), and ICOS data has been and is used in their development. These kinds of models can work on scales from individual plants or trees, to plots, landscapes and up to the global scale. Other examples of DGVMs are:

- NCAR Community Land Model CLM4 (Thornton et al., 2007)
- Hyland (Levy et al., 2004)
- LundPotsdamJena LPJ (Sitch et al., 2003)
- LPJ-GUESS LPJ-GUESS (Smith et al., 2001)
- ORCHIDEE CN (Zaehle et al., 2010)
- ORCHIDEE (Krinner et al., 2005)
- Sheffield DGVM (Cramer et al., 2001)
- TRIFFID (Clark et al., 2011)
- VEGAS (Zeng et al., 2005)

Yet another data-driven approach to evaluate NEE and GPP from vegetation is the FLUXCOM method. FLUXCOM uses machine learning techniques where ICOS-like flux data is essential.

SOCAT (which includes ICOS ocean data) is an important input to the Global Carbon Project's yearly analysis of the global carbon budget, as it forms the basis of GOBM (Global Ocean Biogeochemical) models like CCSM-BEC, NorESM-OC, MITgcm-REcoM2. MPIOM-HAMOCC, NEMO3.6-PISCESv2-gas, NEMO-PISCES and NEMO-PlankTOM5. The Fluxengine model, which relies on the SOCAT dataset, lead to the recent Nature paper by Watson et al., 2020.

Use of ICOS data towards support of satellite observations

The ICOS ecosystem sites are already serving as direct satellite-validation platforms for ecosystem groups. As an example, at the ICOS Science Conference (2020), Jan Pisek presented his group's work on using Digital Hemispherical Photography (DHP) at 20+ ICOS ecosystem sites to calculate the 'Clumping index' (CI) over a diverse range of forests and canopy structures. These CI maps were then used to compare clumping products created from multiple satellites like MODerate resolution Imaging Spectroradiometer (MODIS), Deep Space Climate Observatory Earth Polychromatic Imaging Camera (DSCOVR EPIC) and POLarization and Directionality of the Earth's Reflectance (POLDER) over a wide range of spatial resolutions (500 m to 6 km). They demonstrated how the right spatial representation from each ICOS site helped improve satellite product uncertainty. The vital contribution of ICOS ecosystem sites in creating high quality indices at different scales from satellite data was acknowledged. Many parameters measured by ecosystems sites like NDVI, biomass density, surface temperature and several radiative properties of the surface can be used to calibrate and validate satellite observations.

The calibration/validation of satellite GHGs for the atmosphere is more complex and in its nascent stage. The current satellites that measure GHGs in the Earth's atmosphere focus on measuring total column integrated CO_2, NO_X, CH_4 or SO_2, by analysing the spectrum of light reflected by the Earth's surface. In situ observations like the ICOS towers in all 3 domains have instruments fixed at specific heights (e.g., 300 m, 150 m and 20 m) in the lower troposphere which measure ambient levels or exchange fluxes. This makes existing ICOS measurements and current satellite data incompatible for direct validation as they measure two different quantities: Column-averaged by satellites and ambient mole-fractions by ICOS. There are developments of new active satellites and improved averaging kernels that provide information on the vertical profiles of GHGs that can be retrieved from satellite measurements, so that

concentrations over smaller parts of the atmospheric column can be obtained, these can then be used for direct comparison and calibration/validation with ICOS data.

Currently, solar absorption FTIR-spectrometry is the only ground-based remote sensing technique that has demonstrated the required precision and that measures a similar quantity as satellites (satellites measure absorption of light over the column twice over different paths depending on the solar zenith angle, solar FTIR only once). This technique is used in the global network of FTIR spectrometers (TCCON). Hence, the global TCCON data helps in detecting spatial bias and/or temporal drift in the satellite data. Satellites in polar orbit provide just one single measurement around mid-day per 3-4 days integrated over a relatively coarse pixel of currently 150x150 to 10x10 km, and only for pixels where no clouds are obstructing the light path and aerosol disturbance is low. TCCON installations track the sun and provide almost continuous observations whenever the sun shines into the instrument. Nevertheless, despite the mismatch between in situ and column observations, ICOS GHG observations are used as independent sources to check the performance of models assimilating satellite data and to detect biases. The better precision and accuracy of the surface measurements and the higher signal-to-noise ratio of the signal of sources and sinks in the lower troposphere, make ICOS measurements a key component in inverse modelling. The advantage of greater spatial coverage of satellite observations thus far does not weigh up against the disadvantages of observing tiny variations from a large distance with many disturbing influences, but one can imagine that the satellite information in a data fusion system can be used to upscale the high precision in situ observations.

Remote sensing of the ocean carbon cycle is confined to the ocean surface. Using oceanic GHG measurements (like pCO_2) for calibration/validation have the same challenges as atmospheric in situ data since satellites measure column-averaged GHG concentrations. However, in addition to GHGs measurements, ICOS ocean data also include Essential Climate Variables (ECV) like sea surface temperature (SST), sea surface salinity (SSS) and sea level pressure (SLP) which are used for calibration/validation. Satellite SST, SSS and SLP are made at a single level (i.e., sea surface), so can be used for direct comparisons, as well as calibration and validation with ICOS ocean data. The Committee on Earth Observation Satellites (CEOS) reports the most pressing needs for remote sensing of ocean carbon as "continuity of the current observational methodologies and new satellite missions with improved capabilities". Continuity of current observations, clearly falls within the ICOS goals and objectives and reinforces the importance of observational data for satellite estimation of ocean carbon. In addition to new satellite missions, scientists are using novel and innovative methods to circumvent the limitations of current satellite observations to study the oceanic carbon sources and sinks. At the ICOS Science Conference, Parampil et al., reported isolating the short period fluctuations in CO_2 from NASA's OCO-2 data after removing the large background signal in CO_2. They showed flux-like signatures consistent with oceanic sources in the Pacific Ocean and Indian Ocean and verified the nature of these signatures using in situ data in the regions. Thus, in situ data have the crucial role in confirming the nature of the signals from satellite data and acts in a complementary way to calibration/validation. These innovative methods can easily be reproduced for ICOS-specific regions like the Atlantic Ocean.

Core results from the survey related to Criterion 2

All the station PIs and Central Facility coordinators are also prominent scientists in their specific fields. Hence, survey question of importance of ICOS data was posed to them. Both groups strongly agreed to the statement "ICOS data is Very important in my personal field of science". (Figure 4.10.)

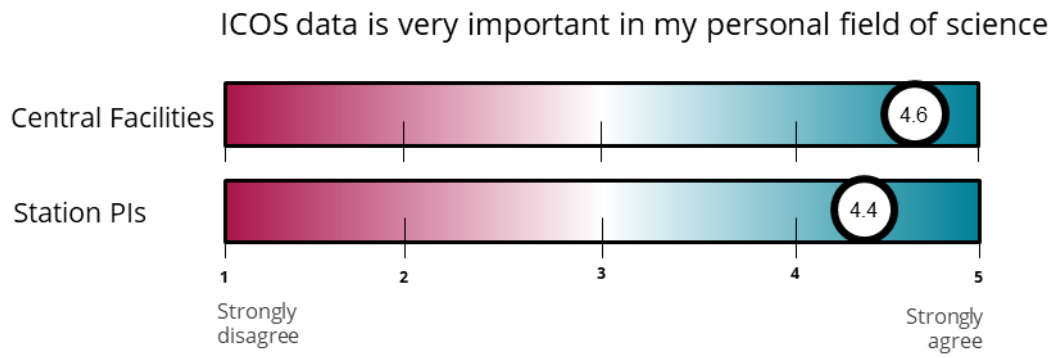


Figure 4.10: Opinions of coordinators of Central Facilities and Stations PIs whether ICOS data is very important on their fields of science.

Evidence for Criterion 3: ICOS data is used in education

Table 4.5: Evidence material for subsection 4.3

Documents available online related to criterion 3	KPI
OTC Training and support	27
ICOS Summer School	27

Documents in Materials folder related to criterion 3	KPI
ICOS trainings 2015-2019	27
List of theses that use ICOS data	27

Usage of ICOS data in educational tools and activities

The ICOS Summer School is organised regularly by ICOS Carbon Portal and University of Helsinki. The school has been organized 2011, 2013, 2015 and 2017, the 2020 class had to be postponed due to COVID-19. First two were in the framework of ESF TTorch and InGOS projects, from 2015 onwards it has been supported by ICOS. The school targets PhD students, Postdoctorate researchers and masters' students preparing for doctoral studies. In 2015 the course had 32 students, in 2017 it had 37 students. For 2020, 35 students registered.

The Thematic Centres organise training events by PIs on how to use hardware and software tools, data processing and quality control theory, etc. The National Networks offer lectures and training events to students outside the ICOS community too. As an example, the annual sensor workshops by OTC:

- 07. - 09. March 2018: in Bergen, Norway. Ca 40 participants
- 25. - 27. November 2019: in Kiel, Germany. Ca 40 participants

- 02. - 04. November 2020: virtual. Ca 25 participants

A quick enquiry to station PIs provided a list of 23 PhD theses, 36 masters' theses and 10 Bachelor's theses in areas of Soil, Water, Atmosphere, hydro sciences and engineering, environmental sciences, geophysics, meteorology, physics, agro-bio technology, forest science and mathematics. The list is not exhaustive, instead is illustrative of the diverse areas where ICOS data can be used. We plan to add a question of new theses to the template of National annual reports from 2021.

4.4 Active Data Promotion and Meeting User/Stakeholder Expectations

Rationale

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.

Objective

The objective is to actively promote data and meet user/stakeholder expectations

Main questions to ask: How well is data promoted and the user/stakeholder expectations met?

Criterion 1: ICOS facilitates successfully scientific initiatives

KPIs for Criterion 1:

KPI 28: Facilitation of scientific initiatives

Criterion 2: ICOS Science Conferences successfully enable scientific exchange

KPIs for Criterion 2:

KPI 29: Enabling scientific exchange through ICOS Science Conferences

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

KPIs for Criterion 3:

KPI 30: Engagement with social- and general media

Evidence for Criterion 1: Scientific initiatives

Table 4.6: Evidence material for subsection 4.4

Documents available online	KPI
Drought Special issue press release and Philosophical Transactions B	28

Survey questions related to criterion 1	Target group
89a/77a. ICOS facilitates science adequately by Organising common initiatives to use ICOS data (e.g., the drought initiative) 89b. ICOS facilitates science adequately by Providing specific data sets for the abovementioned initiatives 89c. ICOS facilitates science adequately by Providing technical services (e.g., the Jupyter notebooks at the Carbon Portal)	Station PIs CF coordinators

ICOS organises initiatives that build on its data, to expand its use and to showcase the potential of the continuous, standardised ICOS observations. Participation is open, and besides the support from ICOS ERIC and Central Facilities, no funding has been available for the participants. Topics typically address recent phenomena of societal relevance, which the traditional research programmes are slow to react to. Below are a few examples of the actions taken. Note that a large part of the stakeholder engagement actions is described in Category 5 of this report, and ICOS Central Facilities also support and co-organise workshops and meetings for external initiatives such as IG^{3}IS and Transcom.

European Summer Drought of 2018: 200 scientists participated in 2018-2020, showing the power of ICOS RI

Over 200 scientists participated in a vast research effort studying the 2018 extreme drought. The effort lasted two years, from mid-2018 to September 2020. The first ideas were conceptualised during informal discussions at the ICOS Science Conference in September 2018, and within weeks, a full-blown research effort was underway. Participating scientists, from all major European universities and research institutes, gathered vast amounts of data utilising the ICOS RI station network and data processing capabilities. The coordination, data processing and practical organisation were supported by ICOS. Further, thanks to the continuous observations of the ICOS stations as well as the personal networks and trust built over the years within the ICOS community, the first data sets were published by ICOS Carbon Portal within 6 months of the first ideas.

The results bring forth new knowledge on the response of vegetation to drought and how the exchange of carbon between the vegetation and atmosphere is affected, providing crucial knowledge when trying to minimise the negative effects of climate change. The studies cover several countries from southern Spain to northern Finland, and from Czech Republic in the east, to the UK in the west. The results, 17 peer-reviewed research papers, were published in a special issue of Philosophical Transactions B, of Royal Society in September 2020. They were also discussed in detail in the ICOS Science Conference 2020 and presented at EGU conferences in 2019 and 2020.

Anomalous Winter of 2019-2020: Research effort uses the ICOS infrastructure to study unusual winter and its consequences

Another example of how ICOS RI facilitates high-quality science, is a new research effort currently underway. With the success of the Drought studies, a group of scientists established a "Winter 2019-2020 Anomaly Study Group" early in 2020, immediately when it was clear the winter of 2019-2020 was anomalous all over Europe, with very warm temperatures. The group includes over 60 scientists from all ICOS countries, and the three ICOS domains.

COVID-19 related research: Scientists use ICOS RI to study changes in anthropologic emissions caused by COVID-19 lockdown measures

ICOS RI also enables scientists to study extreme effects caused by human activity, such as during the COVID-19 pandemic. The lockdowns and other measures put in place due to the virus caused strong reduction in fossil fuel emissions, especially in densely populated areas. Scientists utilised urban ICOS

stations and some non-ICOS stations to study the effects of the pandemic-curbing measures on greenhouse gas fluxes in urban areas. The efforts were led and supported by the ICOS Ecosystem Thematic Centre. The results were first published as a press release by ICOS and on the ICOS webpage in May 2020. They were also discussed in a special session at the 2020 Science Conference, specifically established due to the large number of COVID-19 related abstracts received. The resulting articles are currently under peer-review for publication.

Core results from the survey related to Criterion 1

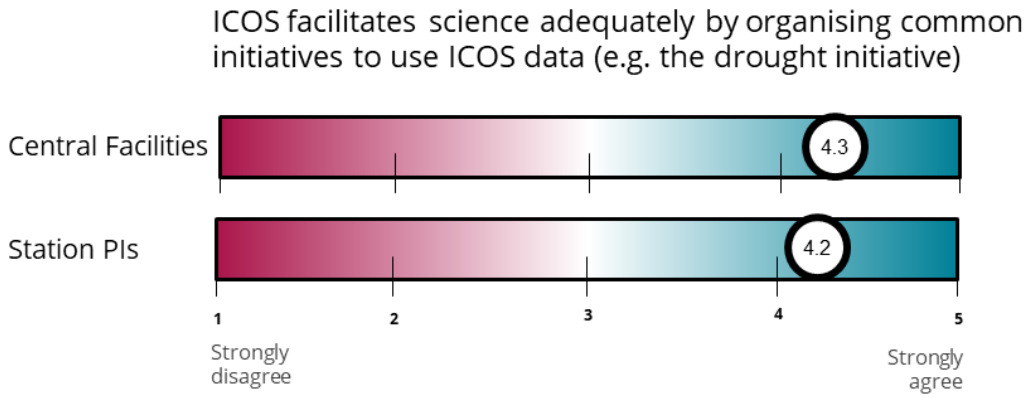


Figure 4.11: Opinions of Central Facility coordinators and Station PIs about common initiatives to facilitate science.

Many of the station PIs and Central Facility coordinators have participated in the Drought initiative, COVID-19 related studies and the ongoing Winter anomaly study. Hence, the survey question on the importance of ICOS data was posed to them. Both groups strongly agreed to the statement "ICOS facilitates science adequately by Organizing common initiatives to use ICOS data (e.g., the drought initiative)" (Figure 4.11.).

Evidence for Criterion 2: Science Conference

Table 4.7: Evidence material for subsection 4.4

Documents available online	KPI
Science conference 2020 highlights.	29

Survey questions related to criterion 2	Target group
90a/77a. The ICOS Science Conference is well organised. 90b/77b. The ICOS Science Conference is important in gathering the ICOS community together. 90c/77c. The ICOS Science Conference is providing a view into the current state of science related to the carbon cycle and greenhouse gases. 90d/77d. The ICOS Science Conference is important in providing information to the general public.	Station PIs CF coordinators

90e/77e. The ICOS science conference is a good opportunity to collect information about recent technical developments from instrument manufacturers.	

ICOS organises the Science Conference to ensure and sustain the highest quality of its science, to promote interdisciplinary and multidisciplinary science between scientists, other experts, policy- and decision-makers. Science Conference also hosts vendor expositions that facilitate updates of the latest research and developments from commercial manufacturers of technological tools.

The ICOS Science Conference is organised every second year: The first was in 2014 in Belgium, then 2016 in Finland, 2018 in Czech Republic and online in 2020. The conference of 2020 was originally supposed to be in Utrecht, the Netherlands, but had to be organised online due to the COVID-19 restrictions. In the spirit of open science, it was also free of charge, which increased the number of participants considerably (Figure 4.12).

Both the number of participants and the number of abstracts submitted have grown steadily from 2014 to 2020.

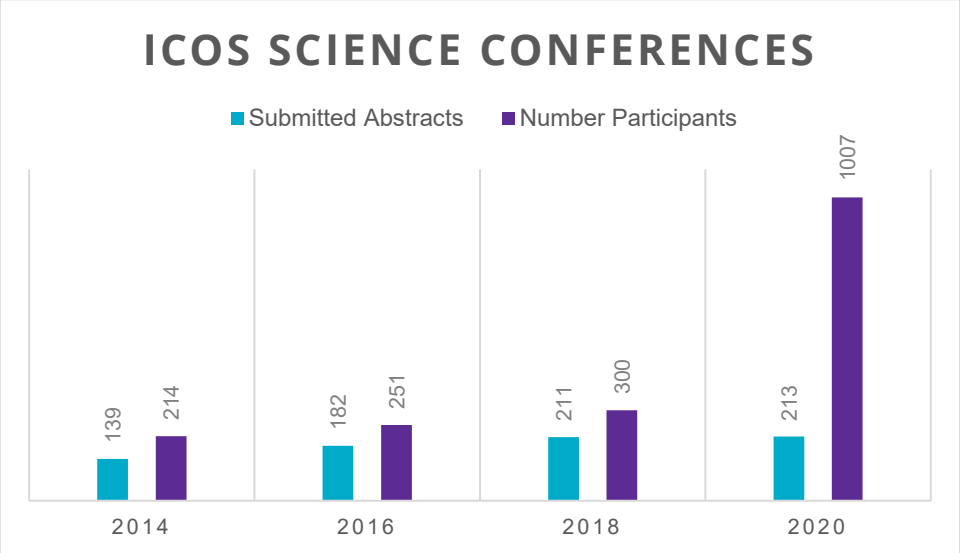


Figure 4.12: Submitted abstracts and number of participants in ICOS Science Conferences.

The majority of the scientific curricula is based on the abstracts submitted according to the conference themes decided by a Programme committee, and announced on the ICOS website. Additionally, ICOS usually invites few internationally recognized keynote speakers, to motivate and encourage scientists to participate in the conference.

Table 4.8: Presentation themes in ICOS Science Conference 2020.

Number	Theme name	Oral	Poster
1	Vulnerability of the Carbon Cycle	10	11
2	Urban observations and detection of human emission	10	17
3	Fluxes at the land-ocean-atmosphere continuum	10	12
4	Innovation and uncertainties in observation techniques	15	12
5	Carbon exchange of atmosphere and reservoirs with long-term storage potential and its verification	5	4
6	Budgets, trends and controls of GHG and other atmospheric constituents	15	24
7	Bridging remote sensing and in situ measurements of GHG and related observations	11	4
8	Education tools and methods	4	2
Extra	Impact of COVID-19 lockdown on anthropogenic emissions	5	0

Over time, the process has evolved based on the experiences from the previous years and takes into account the capabilities and expectations of the local scientific partner. The HO uses an external conference organiser and other external partners for support in arrangements. Lately however, more of the biennially recurring tasks are taken in-house, according to the capabilities developing within the ERIC.

Core findings from the Survey

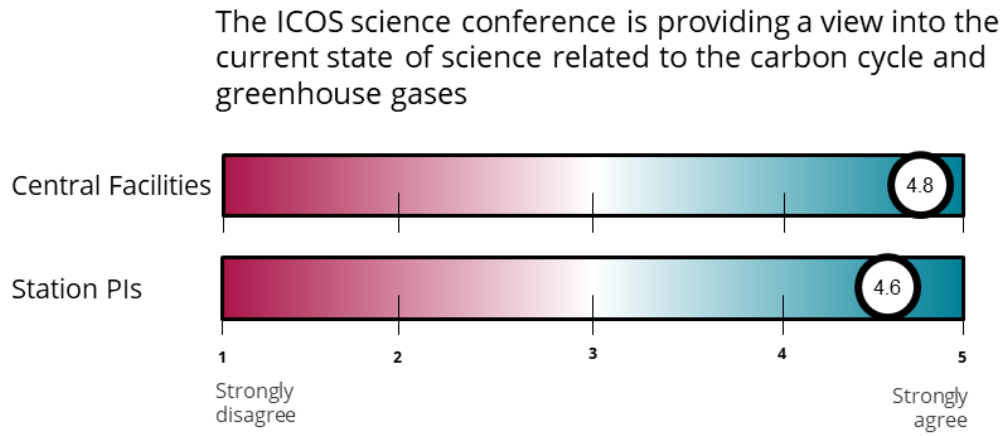


Figure 4.13: Opinions of Central Facility coordinators and Station PIs about the Science Conference.

Many of the station PIs and Central Facility coordinators participated in the Science Conference. Both groups strongly agreed to the statement "The ICOS science conference is providing a view into the current state of science related to the carbon cycle and greenhouse gases" (Figure 4.13.)

Evidence for Criterion 3: Social and general media

Table 4.9: Evidence material for subsection 4.4

Documents available online	KPI
https://icos-ri.eu	30
https://twitter.com/ICOS_RI	30

Stakeholder mapping to find out expectations

To engage especially the non-scientist stakeholder groups and to know more about their needs, ICOS HO started a more in-depth exercise within the RI in autumn 2019. The aim was to study the needs and the expectations of stakeholders more methodically. This stakeholder mapping produced an analysis of the most important stakeholder groups. In addition to ICOS RI operators, the most important stakeholders are academics (scientists etc), hosts of the academics, GHG inventory people, Brussels operations people, supranational organisations in relevant fields, educators and standard makers as well as opinion makers (Figure 4.14). The work was temporarily halted due to the challenges related to COVID-19. However, the next step is to use dialogue and service design methods to find out what the most important stakeholder groups need and expect from ICOS and its data (products).

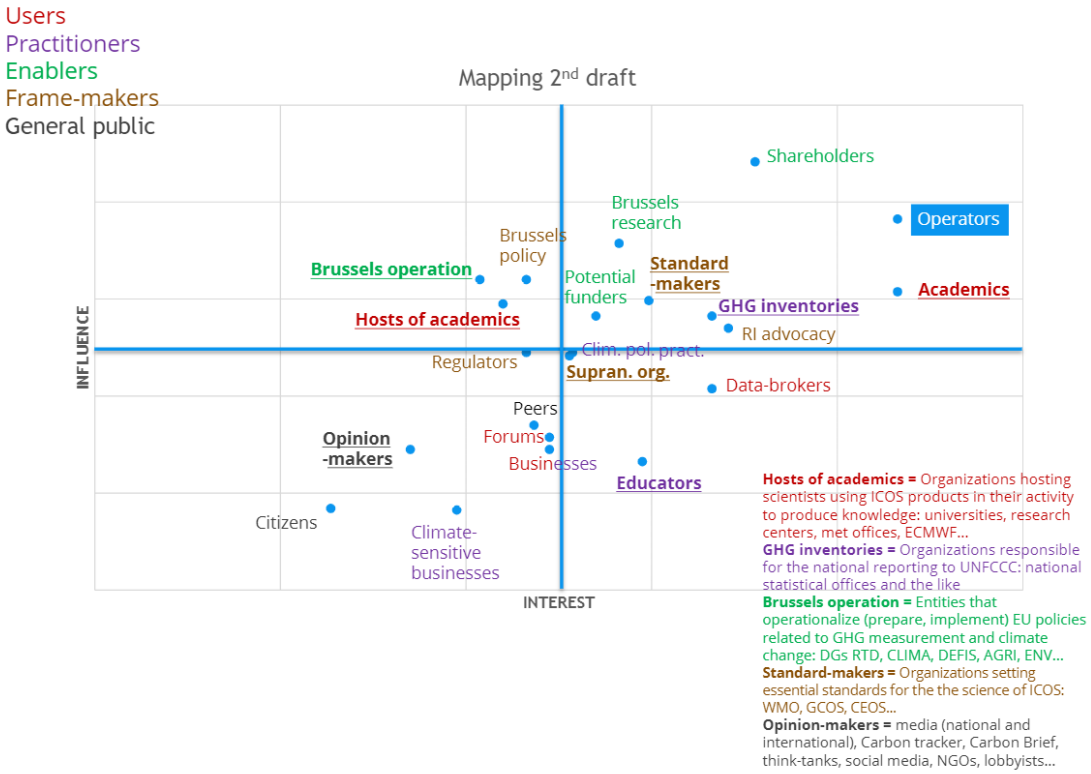


Figure 4.14: The four-square of stakeholders, where they have been mapped according to the influence, they have on ICOS, and on the interest they have in ICOS. Most important ones are marked on bold.

Increasing awareness of ICOS and its data among users and stakeholders

ICOS uses a variety of communications and marketing means to reach its the users and stakeholders.

ICOS website visits have quadrupled since 2017

The combined number of unique views on the ICOS RI (www.icos-ri.eu) and Carbon Portal (www.icos-cp.eu) websites has almost quadrupled in the past three years, from 37 000 views in 2017 to 138 200 views in 2020. The ICOS RI and Carbon Portal websites were merged into a common website in April 2020.

In addition to ICOS website, there are at least 12 other ICOS related websites: Each of the Thematic Centres and almost all the National Networks have their respective websites. These are not hosted by ICOS ERIC, and thus we do not present their statistics here.

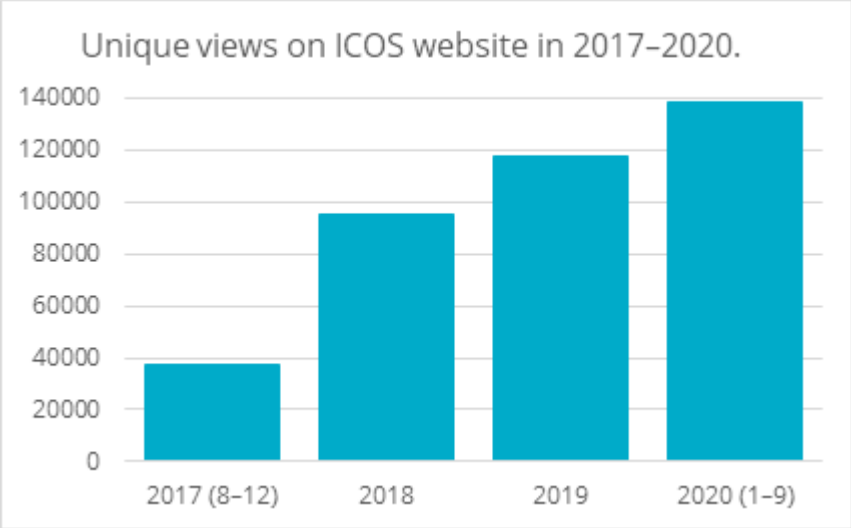


Figure 4.15: The combined number of unique views on ICOS RI and Carbon Portal websites. Note that the Carbon Portal website contains all ICOS data.

Visibility on social media

On social media, ICOS focuses its efforts mainly on Twitter and Instagram. From 2016 to September 2020, the number of ICOS Twitter (@ICOS_RI) followers has grown steadily, gaining circa 300 new followers per year (Figure 4.16).

The number of Instagram followers has grown from zero to circa 2500 within the past four years. Instagram was the main social media platform of ICOS during the ICOScapes campaign in 2017–2018. This explains the enormous increase in the number of followers during those years, followed by a slow decrease of followers since the campaign ended in 2018 (Figure 4.17).

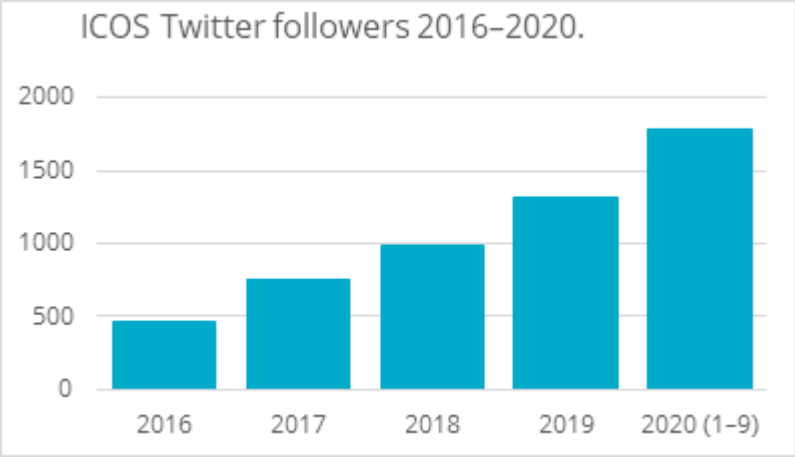


Figure 4.16: The number of followers in ICOS Twitter channel has grown steadily.

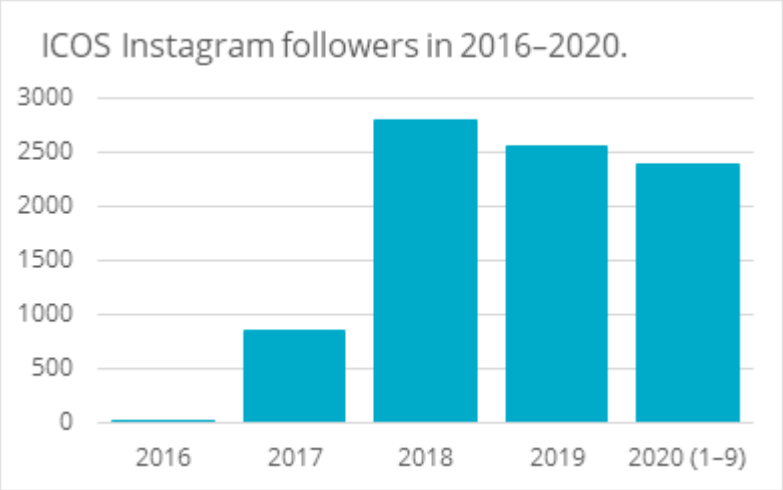


Figure 4.17: The number of followers in ICOS Instagram channel has grown exponentially since 2016, and has slowly decreased since 2018.

Visibility in journalistic media

The number of news articles or stories in general online media concerning ICOS RI has grown steadily since 2016, with exceptionally many articles published in 2018. The reason for the peak was that the first stations in many countries were labelled that year, thus many host institutes made extra efforts for publicity, and the topic was novel and interesting for media. Furthermore, ICOS had a social media campaign with the famous photographer, Konsta Punkka, and by virtue of his fame, the campaign reached the traditional media. The photographer was also interviewed for his other work several times, where he mentioned his cooperation with ICOS often. In 2020, while the number of publications is lower than in 2018 and 2019, ICOS was featured in several media outlets with high reach potential, such as Medium (US, 116 million readers), La Repubblica (Italy, 25.9 million readers), and Wired UK (4.59 million readers). Many of these articles featured research efforts carried out within ICOS, such as the Drought Initiative or the COVID-19 related studies.

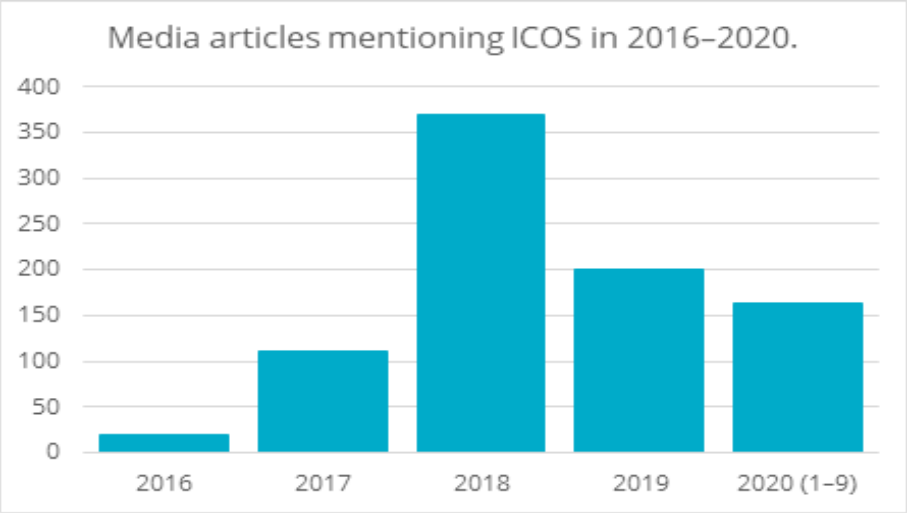


Figure 4.18: The number of media articles mentioning ICOS in 2016–2020.

4.5 Downstream Private Sector Cooperation for ICOS Data Usage

Rationale

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.

Objective

The objective is that ICOS RI cooperates with private sector and/or that ICOS data is used by the private sector.

Main question to ask: How extensively is ICOS data used by the private sector?

Criterion 1: ICOS engages with downstream projects with private sector

KPIs for Criterion 1:

KPI 31: Engagement in downstream projects with private sector

Evidence

Table 4.10: Evidence material for subsection 4.5

Documents available online	KPI
https://www.earthnetworks.com/why-us/networks/greenhouse-gas/	31
https://pemcarbon.com/	31

Documents in Materials folder	KPI
List of participants in the Business Science Forum	31

Earth Networks in Maryland, USA, with clientele such as NOAA, has been interested in ICOS in the PPP phase (i.e., Before ICOS was an established EIRC). Recently they have focused more of their efforts in severe weather. PEM carbon has been in contact with the Ecosystem Thematic Center, they are working on this and presenting the idea and building the business model.

ICOS measurements require high-end instrumentation and technical skills. Therefore, ICOS technicians and scientists are constantly following the latest in Research and Development (R&D) carried out by the private sector. In return our technicians and scientists as users provide valuable insight to the manufacturers of sensors for example. Thus, it has been a natural element to enhance this collaboration between the private sector and ICOS scientists. This interaction takes place in the Vendor Exhibition that is organised as part of the Science Conference.

The number of companies participating in the Vendor Exposition has varied (Figure 4.19) and it was the lowest during 2020 Conference, that was organised virtually.

The testing of new instruments, described in subcategory 1.2, also contains interaction with instrument manufacturers. Instrument manufacturers like LICOR, Picarro, LGR, Gill, ACOEM Ecotech use ICOS data and experiences to develop their equipment. As an example, ICOS Netherlands, Cabauw station and ATC received support from Ecotech for development and testing of the Spectronus FTIR. Based on the provided recommendations they are now producing a ruggedised rack mounted version that is almost in production and will be tested by ATC. Based on the feedback based on experiences and the measurements from 2012 onwards with the FTIR they improved the FTIR temperature control, developed their software and improved their cell characteristics. As a second example, SmartFlux2 from LICOR specification and design have also been based on the feedback and requests from ICOS.

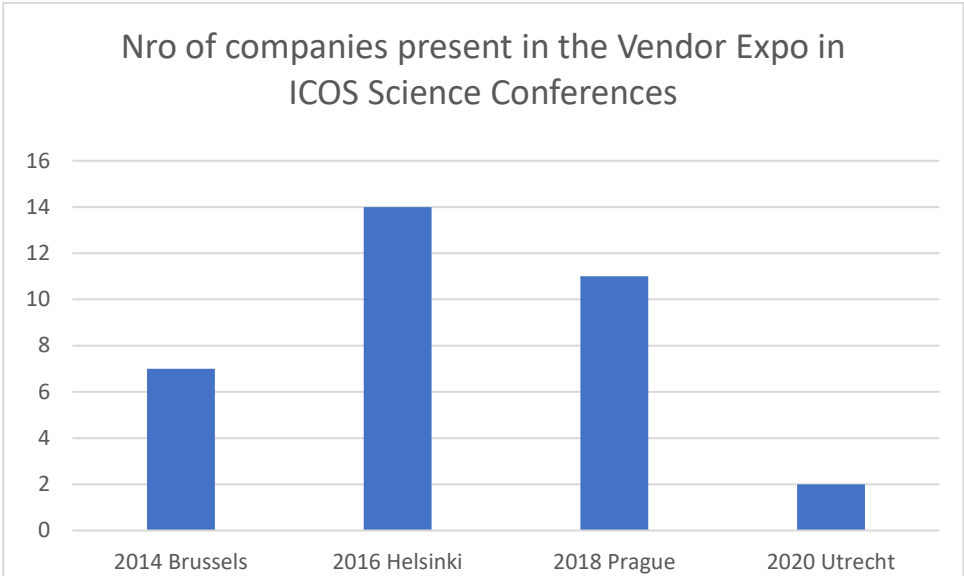


Figure 4.19: Number of private sector companies that has purchased a booth from ICOS Science Conferences. Note that the 2020 Science Conference was organised online.

The ICOS ERIC Head Office keeps a close eye on monitoring the state of the art and participated in Marine Autonomy and Technology Showcase (MATS) in Nov 13-14, 2018. The purpose was to seek more companies that might be interested in participating in the ICOS Science Conference Vendor exposition, but are also interesting for the ICOS community and provide new perspectives as users.

In March 2019 ICOS co-organised a North-Atlantic, Mediterranean and adjacent seas (Baltic Sea) carbon-cycling mini symposium in Southampton. (More details here: Conferences & Events | noc-events.co.uk).

In addition to the mini-symposium, ICOS Ocean MSA organized an 'Industry/Science Observing Forum' in appreciation of the ongoing successful operations with their important Private sector collaborators (i.e., shipping companies and ship owners/operators). Scientific measurements conducted on the SOOP lines are largely based on the goodwill and trust between the ship owners/operators and the scientists. At the forum, both groups met potential collaborators and peers, discussed problems and solutions to ensure frictionless collaboration. The forum had 26 participants, out of which 10 represented different industries.

Category 5: Integration of ICOS in European & Global GHG Information Systems

Rationale

Being a regional research infrastructure in Europe, ICOS needs to integrate into a global system of greenhouse gas observation since greenhouse gases do not 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).

Objective

Objective is that ICOS is well integrated in European and global GHG information systems.

The main question to be asked is:
How well is ICOS integrated in European and global GHG information systems?

5.1 Estimation of the Intensity of ICOS International Cooperation

An operational way to evaluate the intensity of international cooperation was used for this report. After having drawn a landscape of the cooperation actors available, the connections of ICOS with each of them was assessed using a scale from 1 to 3, depending on the intensity of the contacts: from preliminary discussions to common working groups to formal cooperation or common products. A particular set of these cooperation partners are specifically engaged in organising the global response to climate change: UNFCCC, WMO, GEO, etc. The estimation of the cooperation intensity with these actors is an indication of the relevance of ICOS to this endeavour.

Criterion 1: ICOS cooperates with the main actors of the European and global GHG information systems

How well does ICOS cooperate with relevant organisations contributing to improve the GHG information systems in Europe and worldwide?

KPI for Criterion 1:

KPI 32: Cooperation with the main actors of the European and global GHG information systems

The KPI monitors the level of cooperation. It is numerical and is an estimation of the "intensity" of ICOS partnerships based on three levels. The first level signals informal discussions, more formal meetings on specific topics with the partner. Level 2 attests concrete actions, joint participation in working groups, common projects. The third level bears witness to the existence of common products or formal agreements with the partner.

Criterion 2: ICOS is relevant for the global response to climate change

How does the cooperation of ICOS with specific actors show its relevance for the global response to climate change?

KPIs for Criterion 2:

KPI 33: ICOS's relevance in the global response to climate change

The KPI is narrative and focuses on the role and activities of ICOS in global cooperation frameworks addressing climate change issues (such as UNFCCC, GEO, etc.).

5.2 The Individual Level of ICOS Involvement in International Cooperation

More than the contribution of ICOS as an organisation, it is possible to evaluate the level of international cooperation in terms of the participation in events and the contribution of individual members of the ICOS community. The latter covers a too large number of people, but restricting the focus to the individuals playing an official role in the ICOS RI (at the Head Office, the Carbon Portal, the Central Facilities, the Monitoring Station Assemblies, etc.), it is possible to estimate an individual level of involvement.

Criterion 3: ICOS participates in events of regional or global relevance

How often and efficiently does ICOS actively participate in events with a regional or global significance?

KPI for Criterion 3:

KPI 34: Participation in events of regional or global relevance

The KPI is numerical and evaluates the global integration of ICOS, especially with partners that are more in the policy-making domain, through the participation in events of regional or global importance.

5.3 ICOS International Cooperation in the Eyes of the Stakeholders

It is essential to estimate the way the efforts in international cooperation made by ICOS are perceived by the targets of these efforts, i.e., the stakeholders at the European and global levels. In Europe, one of the concrete ways to cooperate with fellow Research Infrastructures is to develop common, co-located measurement stations that can foster synergies between the partners. At the global level, ICOS can engage in more formal cooperation through agreements such as Memoranda of Understanding (MoUs).

Criterion 4: ICOS has common observational sites with other RIs at country level

How extensive is the network of ICOS measurement stations that are common with other Research Infrastructures at the country level?

KPIs for Criterion 4:

KPI 35: Synergies and co-locations with other RIs

The KPI is numerical and counts common locations of measurement sites with other RIs in each of the member countries of ICOS.

Criterion 5: ICOS makes formal agreements (MoUs) with other RIs or organisations

Does ICOS engage in formal international agreements with other Research Infrastructures or organisations?

KPIs for Criterion 5:

KPI 36: Formal agreements (MoUs) with other RIs or organisations
The KPI is numerical and represents the number of formal agreements signed between ICOS ERIC and other RIs or organisations.

Evidence

The survey sent to the stakeholders contained closed questions (with a set of possible answers) which allow for a quantitative analysis (for e.g., x% strongly agree that…). It also contained a significant number (13 out of 29) of open questions that provide a valuable insight on key points. The stakeholders were, for instance, asked to suggest improvements in terms of visibility of ICOS, engagement and contributions of ICOS to their organisations, and efforts to increase international cooperation. A free space was also left for any other comment.

Evidence for Criterion 1: ICOS cooperates with the main actors of the European & global GHG information systems

Table 5.1: Evidence material for subsection 5.1

Documents available online	KPI
ICOS Handbook 2020	32

Documents in Materials folder	KPI
Table 1 in category report 5	32
Table 2 in category report 5	32, 34

Survey questions related to subsection 5.1	Target group
5. ICOS is clearly visible in my work community. 6. How would you improve it? 7. ICOS is engaged in the cooperation with my organisation. 8. How would you improve it? 11. What data, product or service should ICOS provide your organisation to make your work easier? 12. The cooperation of ICOS with other environmental Research Infrastructures in Europe is significant. 13. In European cooperation, more efforts should be put on… 16. ICOS is well engaged within the ENVRI community regarding…	Stakeholders

Core results from the survey related to Criterion 1

The stakeholders were asked to evaluate the cooperation of ICOS in Europe and internationally. Both were rated very high (75% somewhat or strongly agree in Europe, 84% globally). On the European level (Figure 5.1), the areas that ICOS should develop in common with other RIs are primarily co-locations and common data facilities (67% somewhat or strongly agree), followed by joint research projects and common organisational structures (50%). Sharing (33%) or exchanging (42%) personnel is less favoured. If all answers related to the ENVRI Community are mostly positive, half of the respondents have no clear

position. The role ICOS in the representation of ENVRI towards the actors related to the European Commission is very favourably judged by 25% of the respondents.

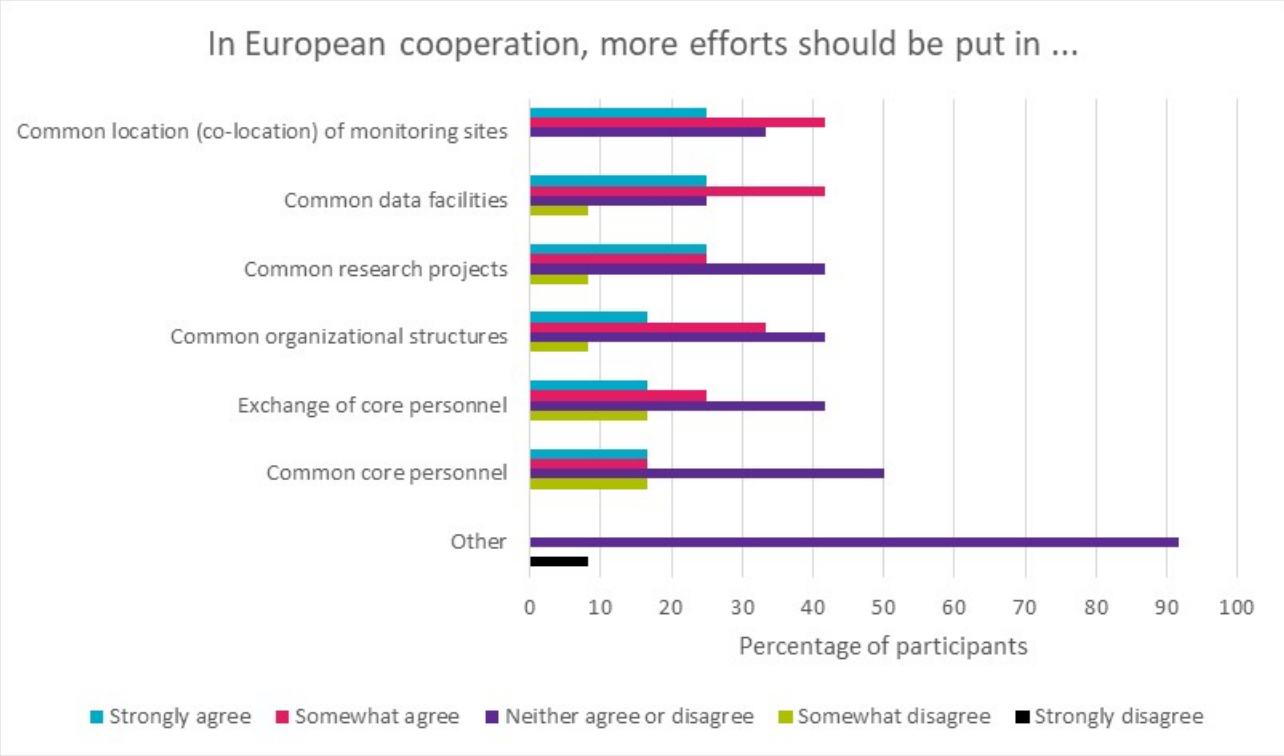


Figure 5.1: Results of the survey question 13 "In European cooperation, more efforts should be put on..."

On the global level, 84% of the respondents somewhat or strongly agree that the cooperation of ICOS with other environmental RIs is significant. If more efforts should be made (Figure 5.2), they should concentrate on standardisation and common protocols (59% strongly agree). Common data facilities or data integration projects are highly ranked (34% strongly, 50% somewhat agree), common research projects and exchange of core personnel are also favoured (17% strongly, 58% somewhat agree). The co-location of monitoring sites seems to be more problematic: If 58% somewhat or strongly agree, 25% express a somewhat negative view.

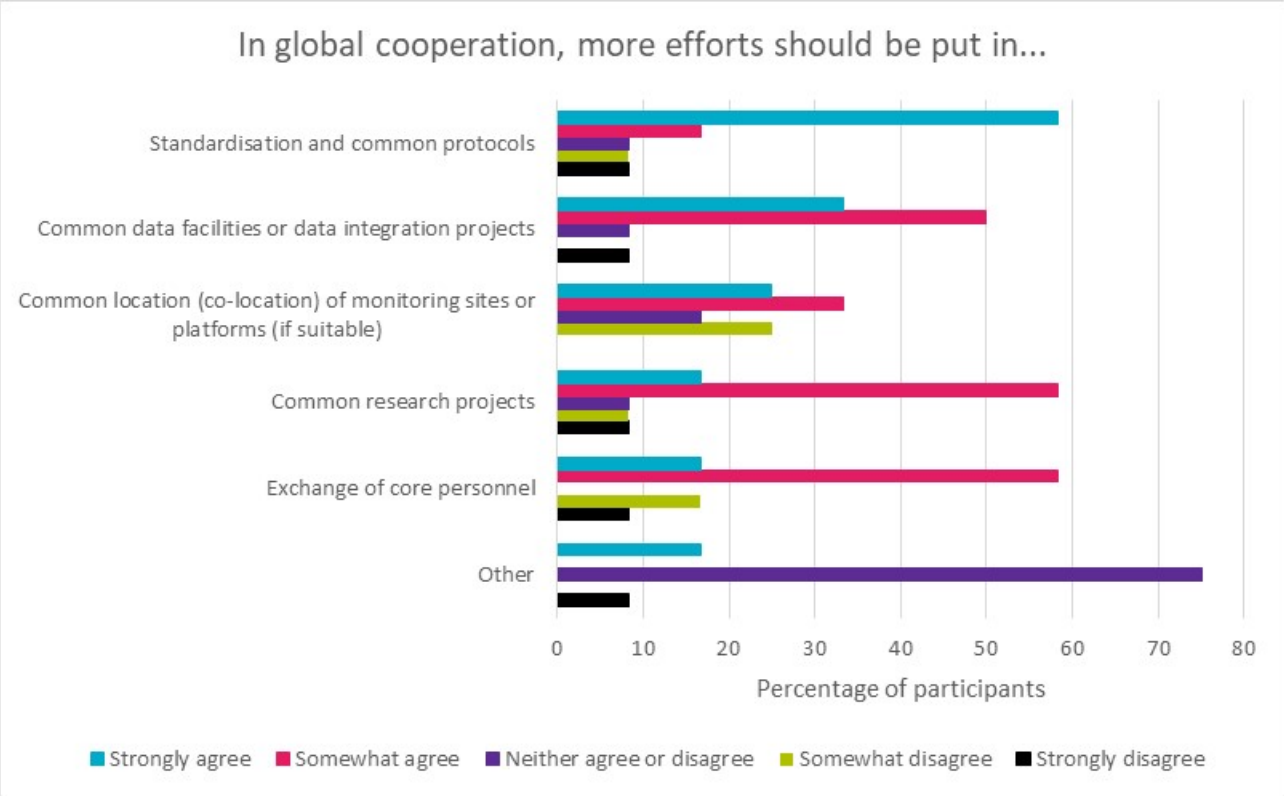


Figure 5.2: Results of the survey question 18 "In global cooperation, more efforts should be put in..."

Evidence for Criterion 2: ICOS is relevant for the global response to climate change

Table 5.2: Evidence material for subsection 5.1

Documents available online	KPI
ICOS Handbook 2020	33

Survey questions related to subsection 5.1	Target group
1. Global carbon cycle and GHG observations system is important in support of climate action. 2. An organisation like ICOS is relevant in the global response to climate change. 4. It is important that ICOS provides climate-change-related knowledge to... 17. The cooperation of ICOS with other environmental Research Infrastructures globally is significant. 18. In global cooperation, more efforts should be put on... 21. The role of ICOS and ICOS data in the design of the European climate policy is important. 22. If you disagree, what are the areas of improvement? 23. The role of ICOS and ICOS data in global products such as the Greenhouse Gas Bulletin (WMO), or the Global Carbon Budget, is important. 24. If you disagree, what are the areas of improvement?	Stakeholders

25. ICOS has notable added-value to the global climate action. 26. What data, product or service should ICOS provide as tools for international negotiations? 27. The following issues are challenging for the global response to climate change…	

Core results from the survey related to Criterion 2

The raison d'être of ICOS is confirmed: all respondents strongly agree that ICOS is relevant for the global response to climate change and 83% somewhat or strongly agree that ICOS has a notable added-value to the global climate action. For 67%, ICOS and its data play an important role in global products such as the Greenhouse Gas Bulletin (WMO), or the Global Carbon Budget. ICOS and its data are important in the design of the European climate policy for 83% (somewhat or strongly agree).

Regarding the roles of ICOS (Figure 5.3), the largest support goes to the provision of observational data (92% strongly agree), followed by the standardisation of protocols and data curation and QC (75%). The integration over domains (50%) and the development of data products (33%) gather slightly less support.

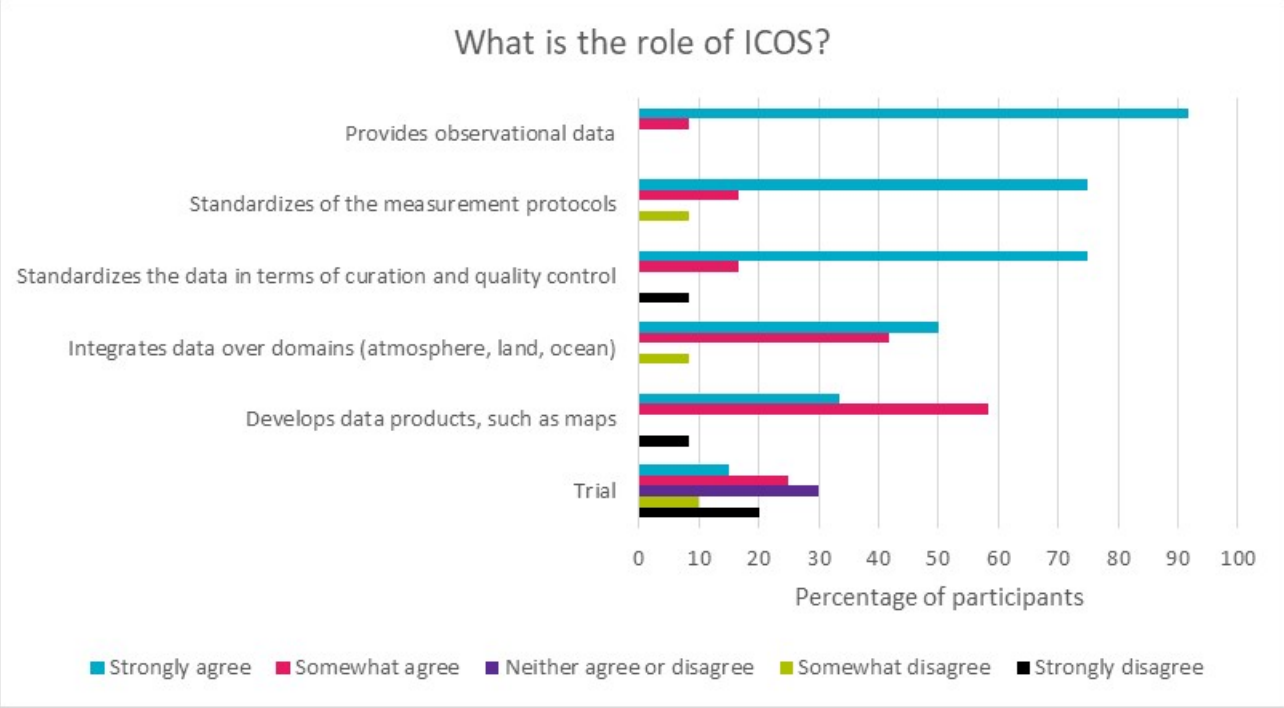


Figure 5.3: Results of the survey question 3 "What is the role of ICOS?"

The "customers" of ICOS (Figure 5.4) should mainly be scientists (92% strongly agree), followed by decision-makers and agencies in charge of GHG inventories (75%). Organisations in charge of assessment of climate change and policy-briefing (50%) and the general public (33%) are not considered as crucial.

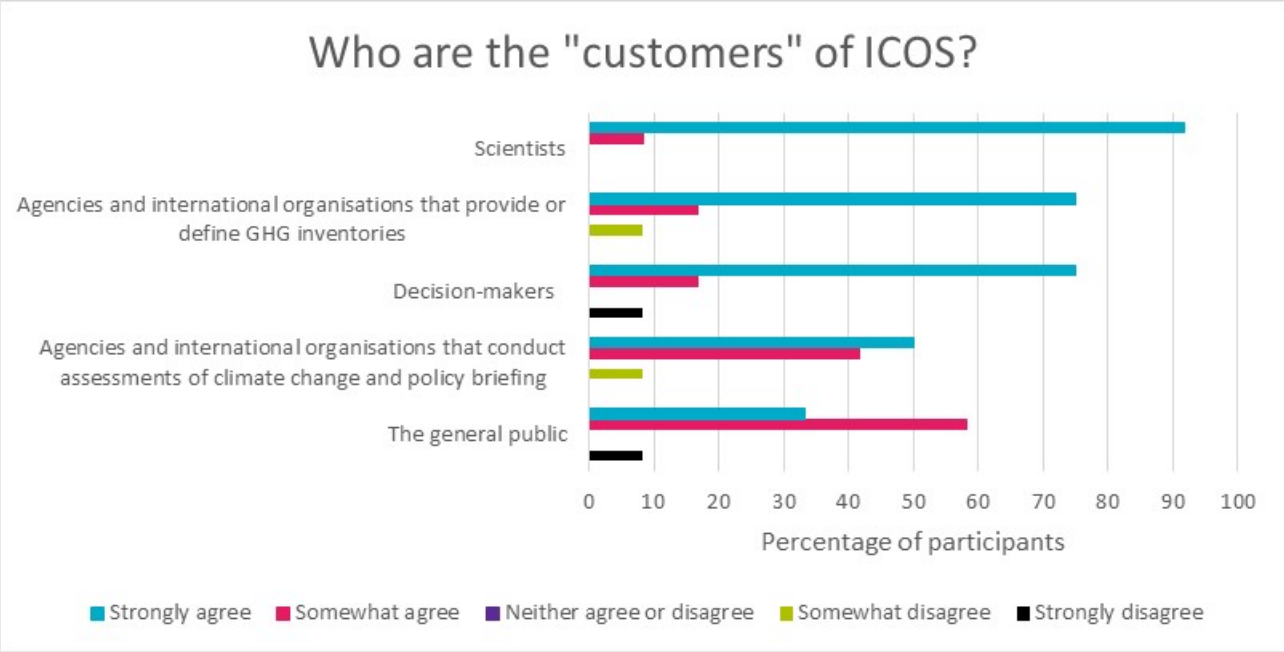


Figure 5.4: Results of the survey question 4 "Who are the customers of ICOS

As the main challenges to the global response to climate change, the respondents see interoperability of the data (84% strongly agree), their reliability (58%) and their accessibility (41% strongly agree, 42% somewhat).

Some respondents see ICOS as a representative who should be a voice for RIs in Europe: "ICOS has an important role in advocating the importance of [standardised accurate quality-controlled observations of greenhouse gas concentrations and fluxes] to EU member states, who are ultimately responsible for the financing of these observations".

For climate negotiations, ICOS should provide high-quality, long-term data as well as support efforts for regions with observational gaps. One respondent gives an extensive answer: "The best possible data on the carbon cycle, both natural and the anthropogenic perturbation, on appropriate scales (which often means on national or sub-national scales). Are the actions taken showing the desired effect? Do observations support national reports on NDCs? Support Global Stocktake on adaptation and mitigation? The data and products need to be available in a timely manner, and regularly. Meaning that the appropriate RIs need to be in place with a funding horizon long enough to make it happen".

One respondent has a clear view of the role ICOS should play in the future: "The landscape related to GHG observations is rapidly changing. While so far most of the focus has been on improving our understanding of the carbon cycle, there is more and more political and societal demand to also monitor and quantify the anthropogenic component. ICOS has an important role to play here, being one of the direct interfaces between national funding agencies, the scientific community, and the policy sector. The European in situ infrastructure will have to be adapted and extended to fulfil the new requirements in addition to the existing requirements. ICOS will be pivotal in making this change happen".

Evidence for Criterion 3: ICOS participates in events of regional and global relevance

Table 5.3: Evidence material for subsection 5.2

Documents available online	KPI
ICOS Handbook 2020	34

Documents in Materials folder	KPI
Table 2 in category report 5	32, 34
Table 3 in category report 5	34

Survey questions related to subsection 5.2	Target group
9. I am satisfied with the contribution ICOS provides to the events I organise 10. How would you improve it?	Stakeholders

One respondent suggests ICOS should select one or two axes to widen its horizons and focus on them to reach actionable effects. An interesting suggestion is also to organise "joint meetings between the executive groups of ICOS and my organisation for us to better understand the scope of ICOS and terms of its funding". This shows that there are still unclarities that ICOS should lift. Overall, the presence of ICOS at strategic places (the media, major U.S. conferences, general assemblies or scientific meetings of other Ris, etc.) could help boost collaboration and align strategies. A respondent also stresses that there are increasing numbers of international initiatives to support the Paris Agreement, with a concurrent need "to agree on (new) ways of collaboration".

Core results from the survey related to Criterion 3

A set of questions were related to the interactions of ICOS with the organisation of the respondent. There, the distribution of answers is broader, with a significant number of respondents (between 17% to 42%) neither agreeing nor disagreeing with the statements. The visibility of ICOS is strong for only 25% of the respondents and the engagement of ICOS for 33%. Half of the respondents are somewhat satisfied with the contribution provided by ICOS to their own events.

One respondent recognises that they have not placed particular demands on ICOS but the engagement they have had so far has been positive. Another one is more explicit: "I'm very happy with the support for events, and flexibility to be inclusive". Another European RI points to direct collaborations and co-located stations and thinks "we should strive towards integrated observational platforms". One respondent is critical and expresses concern over ICOS being "perceived as self-serving and elite". One insists on the use of joint meetings to improve collaboration opportunities, another one on more integration into global databases for carbon, "so that data is available jointly across organisations in formats relevant to different communities".

Evidence for Criterion 4: ICOS has common observational sites with other RIs at country level

Table 5.4: Evidence material for subsection 5.3

Documents available online	KPI
ICOS Handbook 2020	35

Survey questions related to subsection 5.3	Target group
13. In European cooperation, more efforts should be put on… 18. In global cooperation, more efforts should be put on…	Stakeholders

Core results from the survey related to Criterion 4

There was no direct question in the surveys related to the number of common observational sites with other RIs, this was just one of the possible targets where more efforts should be put on. As was mentioned previously (and visible in Figures 5.1 and 5.2), 67% of the respondents somewhat or strongly agree that, on the European level, ICOS should develop co-locations with other RIs. The picture is more unclear on the global level: If 58% somewhat or strongly agree, 25% express a somewhat negative view.

Evidence for Criterion 5: ICOS makes formal agreements (MoUs) with other RIs or organisations

Table 5.5: Evidence material for subsection 5.3

Documents available online	KPI
ICOS Handbook 2020	36

Documents in Materials folder	KPI
GA12 GERI	36
Signed MoU GERI	

Survey questions related to subsection 5.3	Target group
14. There is the need for formal agreements with other RIs in Europe. 15. Please, specify why? 19. There is the need for formal agreements with other RIs globally. 20. Please, specify why?	Stakeholders

Core results from the survey related to Criterion 5

The respondents have few suggestions on where to put more efforts, but the value of international partnerships is stressed in many answers. The need for ICOS to formalise these partnerships is debated. In Europe, 50% of the respondents are somewhat or strongly in favour of formal agreements, while 42% neither agree nor disagree. The open answers vary also: some respondents are "generally fan of bottom-up and grassroot efforts" or think that "more important is maybe cooperation", whereas others see formalised agreements as ensuring "cost efficiency", "better integration" and "guarding from inertia" through the setting of action plans, timelines and deliverables.

The situation at the global level is more in favour of formal agreements (67% somewhat or strongly agree, 33% neither agree nor disagree). They "provide for common aims, which ensures harmonisation so that collective data can be used at multiple scales for prediction, policy and management" and they "allow reporting to funding agencies on collaborations and globally-applicable research". One respondent, however, suggests that "it is difficult to reach "formal agreements" with international RIs, maybe it is not even needed". The explanation is given by another respondent: "International RIs have different mandates, cultures, sources of funding". The same adds, however, that "such agreements help align the collaborative efforts around the world. Not only within the northern hemisphere and developed countries". This is also stressed by another respondent: in Europe, agreements are needed "to establish more effective collaboration across – now still isolated – entities providing different data on the environment". Europe is, according to one respondent, the place where a better organisation of

the collaboration between RIs is the priority. Another respondent considers that “collectively, what ICOS is trying to do is outside its European Geo-political boundaries. International agreements also place ICOS’s and EU’s effort into a global context”.

One respondent suggests that ICOS should engage in “membership of initiatives that strive for harmonisation, comparability and interoperability” while another stresses the fact that the diversity of situation in other regions of the world must be taken into account when advocating standardisation efforts. As put by another respondent on the same issue: “Global standardisation of observations is a great idea but many researchers based in other countries would not be able to have experimental settings as required by the standardisation. Thus, alternatives should be thought considering the economic reality of other nations”.

Terms and definitions

TERMS	DEFINITIONS
Carbon Portal	Carbon Portal is the combined real and virtual data centre in which ICOS observational and elaborated data products and associated metadata are stored, archived, accessed and curated.
DANUBIUSPP	DANUBIUS-PP is an EU Horizon 2020 project to raise DANUBIUS-RI (the International Centre for Advanced Studies on River-Sea Systems) to the legal, financial and technical maturity required for its successful implementation and development.
Data Policy	Data Policy is a document and an internal rule that sets out the principles for the handling of and access to data and e-science tools within the ICOS Research Infrastructure as well as the rights and obligations of data providers and users.
ENVRIFAIR	ENVRI-FAIR is a Horizon 2020 project. Its overarching goal is to implement the FAIR (Findable, Accessible, Interoperable, Reusable) principles in the ENVRI (Environmental Research Infrastructures) community and to connect it to the European Open Science Cloud (EOSC). The final aim is to provide an open-access platform for interdisciplinary environmental research data in the European Research Area utilising the EOSC.
ENVRIplus	ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe.
FAIR principles	The FAIR Data Principles are a set of guiding principles in order to make data findable, accessible, interoperable and reusable. These principles are applied on the ICOS data.
EUDAT (European Data Infrastructure)	EUDAT's vision is that data are shared and preserved across borders and disciplines by enabling data stewardship within and between European research communities through a Collaborative Data Infrastructure (CDI), a common model and service infrastructure for managing data that spans all European research data centres and community data repositories.
FLUXNET	FLUXNET is a global network of micrometeorological tower sites that use eddy covariance methods to measure the exchanges of carbon dioxide, water vapor and energy between terrestrial ecosystems and the atmosphere.
Host Contribution	Host Contribution is the financial support of Members or Observers hosting an ICOS Central Facility.
Host Premium Contribution	Host Premium Contribution is the financial support of Members or Observers hosting an ICOS Head Office and Carbon Portal.

ICOS Research Infrastructure (ICOS RI)	ICOS Research Infrastructure is the distributed research infrastructure that is coordinated by ICOS ERIC and involves Central Facilities and ICOS NNs (National Networks).
ICOS Central Facilities (CFs)	The CFs are the centres analysing samples and/or processing data obtained from ICOS NNs (National Networks), supporting and supervising them and performing technological surveillance on sensors and methods.
ICOS Thematic Centres (TC)	ICOS Thematic Centres include the Atmosphere (ATC), Ocean (OTC) and Ecosystem Thematic Centres (ETC), which help the ICOS monitoring stations in their work. Each TC works within the respective domain with the respective observational network. Together with Carbon Portal and Central Analytical Laboratories (2) they form the Central Facilities.
ICOS Central Analytical Laboratories (CALs)	The ICOS Central Analytical Laboratories (CALs) are located in Germany and consist of two laboratories: The Flask and Calibration Laboratory (FCL) in Jena, which is hosted by the Max Planck Institute for Biogeochemistry, and the Central Radiocarbon Laboratory (CRL) in Heidelberg, which is operated by the Institute of Environmental Physics of the University of Heidelberg.
ICOS Data	ICOS data are quantitative or qualitative attributes of variables or sets of variables that have been gathered using ICOS-recommended sensors at validated ICOS stations. The measurements are standardised due to protocols mutually agreed upon.
ICOS Level 0 data	Level 0 or raw data are data that are directly obtained from human measurements or automated sensors that have not undergone any transformation.
ICOS Level 1 data	Level 1 are intermediate observational data. These data are generated in intermediate steps in the data processing of Level 1 NRT (Near Real Time) or Level 2 data preparation, and for this reason they are not handled as persistent data and not shared outside the ICOS RI.
ICOS Level 2 data	Level 2 data are final quality controlled observational data. Level 2 data are the main product of ICOS and form the final, quality-checked ICOS RI dataset, published by the Central Facilities, to be distributed through the Carbon Portal. Also known as ICOS labelled data.
ICOS Level 3 data	Level 3 data are also known as elaborated data products. Scientific communities create elaborated data products that rely partly or completely on ICOS data products.
Metadata	The dataset that describes the data are called metadata. They are important for the usability and transparency of data.
Ancillary data	Ancillary data are data that are added in the data product and add contextual information in the data.
ICOS National Networks (NNs)	ICOS ERIC Member countries' Atmosphere, Ecosystem and Ocean networks of measuring stations.

ICOS Research Infrastructure Committee (ICOS RICOM)	RI COM is the advisory body for the Director General of ICOS ERIC in all general matters to ensure the consistency, coherence and stability of the Research Infrastructure; it includes one representative from the Head Office, Carbon Portal, each ICOS Central Facility and each Monitoring Station Assembly.
ICOS Station, Measuring station	An observatory in an ICOS NN that has been labelled by ICOS ERIC and follows the standardised measurement protocols and quality-assurance and data- management plans defined in ICOS' internal technical and scientific documents. An ICOS station may be labelled for atmospheric, ecosystem or oceanic research purposes. There are both Class 1 and Class 2 stations, which are defined in the Scientific and Technical Description. The ICOS RI network consists of 144 (in May 2020) measuring stations located in twelve countries in Europe.
ICOS Class 1 Station	(For Ecosystem and Atmosphere stations.) Has complete equipment for measuring the full set of ICOS core parameters.
ICOS Class 2 Station	(For Ecosystem and Atmosphere stations.) Has the same analytical precision as a Class 1 station but measures fewer physical parameters than a Class 1 station.
ICOS Associated Station	(For Ecosystem stations). Measures a selection of parameters and has fewer obligations towards data submission and standards than Class 1 and Class 2 stations.
Internal Financial Rules (IFR)	IFR is the document setting out the general financial principles of ICOS ERIC and the ICOS RI, in particular rules regarding the day-to-day management of financial matters, financial contributions to ICOS ERIC and financial reporting.
Monitoring Station Assembly (MSA)	MSA is an assembly of scientific and technical experts from the ICOS NNs; there is one MSA for each thematic area (Atmosphere, Ecosystem and Ocean).
Spatial Coverage	Spatial coverage describes the geographic area that is covered with ICOS observations. It has two aspects: overall area covered by ICOS observations and the density of network within each country.
Temporal Coverage	Temporal coverage describes the time a station provides data, or vice versa, the number of gaps in the data.
VERIFY	VERIFY is a Horizon 2020 project that aims to provide a pre-operational, observation-based system for the monitoring and verification of greenhouse gases (GHGs).
Director General (DG)	The ICOS DG carries out the day-to-day management of ICOS ERIC and is responsible for the implementation of the decisions of the General Assembly. The Director General is responsible for managing the staff and activities of the Head Office and the Carbon Portal.
General Assembly (GA)	The GA Governs ICOS ERIC and e.g. appoints the Director General.
Evaluation Board, Evaluation Committee	The Evaluation Committee, that was selected by the General Assembly, includes expert scientists and managers from relevant fields. They were

	responsible of creating the evaluation outline in cooperation with the HO and the GA.
Standardisation, Station standardisation	ICOS has developed a broad range of standardisation protocols in order to ensure the highest observational standards for each ICOS station.
Labelling, Station labelling	All ICOS stations go through a two-step station labelling process to get certified. It is performed by the Thematic Centres. Step 1 includes the overall evaluation of the site, tower location etc. and Step 2 includes a thorough analysis of compliance with ICOS standards, measurement setup, data transfer and quality. The labelling ensures all ICOS stations follow ICOS standardisation.
Domain	ICOS stations operate in three areas: Atmosphere, Ecosystem and Ocean, which are referred to as domains.
Heads of Units	ICOS Head Office organisation is divided into units (Operations, Communications, Administration…) and their leaders are referred to with the title Head of Unit.
Evaluation	1. Every five years an independent panel of international external evaluators of the highest quality, appointed by the General Assembly, shall carry out: (a) scientific and management evaluations of the activities of ICOS ERIC; (b) evaluation of ICOS RI activities, scientific and strategic orientation and operation of all components of ICOS RI. The panel shall give special attention to the fulfilment of user requirements. 2. The results of the evaluations referred to in paragraph 1 shall be reported to the General Assembly.
ICOS Statutes	The memorandum of association of ICOS ERIC. It is the document setting out the operational principles of ICOS ERIC. Together with the Financial Rules of the ICOS RI, the statutes set the principles for the calculation of the annual Member and Observer contribution to ICOS ERIC. In addition, they list the member state rights and obligations and ICOS ERIC tasks and activities.
Key Performance Indicator (KPI)	A Key Performance Indicator is a measurable value that demonstrates how effectively a company is achieving key business objectives. Organisations use KPIs at multiple levels to evaluate their success at reaching targets. Since ICOS is a non-profit organisation, many of the KPIs applied are not numeric, but narrative. KPIs are used to demonstrate the materialisation of the core activities.
Key Impact Indicator (KII), impact indicator	A Research Infrastructure, such as ICOS, aims to have an impact on society and that can be evaluated by a set of indicators called Key Impact Indicators (KIIs). They are used to demonstrate the materialised impact the RI's output has on society.
Readiness of ICOS for Necessities of integrated Global Observations (RINGO)	RINGO is a 4-year Horizon 2020 project with a total budget of 4,719,680.00 euros. RINGO has 43 partners in 19 countries and consists of 5 work packages with specific emphasis on the further development of the readiness of ICOS Research Infrastructure (ICOS RI) to foster its sustainability.

Horizon 2020 (H2020)	Horizon 2020 is the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available over 7 years (2014 to 2020) – in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market.
European Strategy Forum on Research Infrastructures (ESFRI)	ESFRI is a strategic instrument to develop the scientific integration of Europe and to strengthen its international outreach. It supports a coherent and strategy-led approach to policy-making on research infrastructures in Europe, and facilitates multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level.
ESFRI Landmark	The ESFRI Landmarks are RIs that were implemented, or reached an advanced Implementation Phase, under the Roadmap and that represent major elements of competitiveness of the ERA. The Landmarks can be already delivering science services and granting user access, or can be in advanced stage of construction with a clear schedule for the start of the Operation Phase. The Landmarks need continuous support and advice for successful completion, operation and – if necessary – upgrade to achieve optimal management and maximum return on investment.
ESFRI Roadmap	ESFRI has established a European Roadmap for research infrastructures for the next 10-20 years, stimulates the implementation of these facilities, and updates the roadmap as needed. The ESFRI Roadmap contains probably the best European science facilities based on a thorough evaluation and selection procedure. It combines ESFRI Projects, which are new research infrastructures in progress towards implementation, and ESFRI Landmarks, successfully implemented Research Infrastructures. The document also describes the broader Landscape of research in Europe which is an important component to ESFRI methodology.
Environmental Research Infrastructures, projects, networks and stakeholders Community, ENVRI Community	ENVRI Community is a Horizon 2020 project aiming at creating a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe.
ENVRIplus	ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe.
European Research Infrastructure Consortium (ERIC)	ERIC is a specific legal form that facilitates the establishment and operation of Research Infrastructures with European interest. The ERIC allows the establishment and operation of new or existing Research Infrastructures on a non-economic basis. The Commission provides practical guidelines to help potential applicants. The ERIC becomes a legal entity from the date the Commission decision setting up the ERIC

	takes effect. An ERIC can carry out some limited economic activities related to this task.
Principal Investigator, Station PI	A Principal Investigator is the individual responsible for the preparation, conduct, and administration of a research grant, cooperative agreement, training or public service project, contract, or another sponsored project. At ICOS the Station PIs run the measuring stations.
Focal Point (FP)	A Focal Point is a country representative and a national coordinator of a National Network.
ICOS Stakeholder	ICOS Stakeholders are especially ICOS RI operators, academics (scientists etc), hosts of the academics, GHG inventory people, Brussels operations people, supranational organisations in relevant fields, educators and standard makers as well as opinion makers that cooperate with ICOS.
Stakeholder mapping	To engage especially the non-scientist stakeholder groups and to know more about their needs, ICOS HO started a more in-depth exercise within the RI in autumn 2019. The aim was to study the needs and the expectations of stakeholders more methodically. This stakeholder mapping has produced an analysis of the most important stakeholder groups.
Co-location	Co-location means that e.g., ICOS sets up measuring devices with another Research Infrastructure on common monitoring stations. They are called common monitoring stations or co-located sites.
Models, climate models	Climate models are based on well-documented physical processes to simulate the transfer of energy and materials through the climate system. Climate models, also known as general circulation models or GCMs, use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, land. Building and running a climate model is complex process of identifying and quantifying Earth system processes, representing them with mathematical equations, setting variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers.
Satellite calibration and validation	Calibration is defined as the process of determining the quantitative response of a system or measuring instrument, to known and controlled inputs. It is the fundamental process by which an instrument is given the capability to perform measurements that are traceable to international standards, giving credibility to measurements performed with the calibrated instrument. The EO system can only deliver true value if the data products are trusted, adopted and applied by the user community. For this reason, a wider quality assurance function, validation, is needed. Validation is being able to confirm that the data products are reliable and fit for the purpose for which they were originally conceived and developed. The end goal of validation is the trust, adoption and application of the EO data products by the user community.

Scientific Advisory Board (SAB)	The SAB was established by the General Assembly. The role of the SAB is to give feedback and make recommendations to develop ICOS RI activities on the scientific level, to advise ICOS ERIC on objectives in achieving the scientific goals of the ICOS RI, to provide programmatic support by commenting at overall science plans and directions, and to analyse the scientific results and impact of the ICOS RI.
Ethical Advisory Board (EAB)	The EAB was established by the General Assembly. The role of the EAB is to advise and periodically report on ethical issues, such as scientific ethics, data-related ethical issues, discrimination issues or any kind of conflict of interest.
Calibration gas	A calibration gas is a reference gas or gas mixture used as comparative standard in the calibration of analytical instruments, like gas analysers or gas detectors.
Gas analysis	Gas analysis is a method for measuring the concentration of gases e.g., in the atmosphere.
World Meteorological Organisation (WMO)	WMO is a specialized agency of the United Nations (UN) with 193 Member States and Territories. It is the UN system's authoritative voice on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the weather and climate it produces and the resulting distribution of water resources.
Research infrastructure (RI)	A Research Infrastructure supports organised research and researcher education while maintaining and developing the host institution's research capacity. Typical components of research infrastructures include 1) Equipment, research and measuring stations, research vessels, specialised laboratories, 2) Research material collections and databases, archives and libraries, 3) Communication networks, high-performance computing centres, other IT capacity, and 4) Infrastructure maintenance and upkeep as well as support services for users.
ICOS Management Plan	The Management Plan document provides an overview of the management structure of ICOS RI. The managerial work during the first five years has resulted in a collection of internal rules and management documents. The rules and policies developed during the design and implementation phase are currently integrated into a comprehensive Management Plan (first draft presented to the General Assembly in November 2020).
Standard Operation Procedure (SOP)	The SOPs are referred to as "ICOS approved operation practices". They provide a set of step-by-step instructions compiled by an organization to help workers carry out routine operations. SOPs aim to achieve efficiency, quality output and uniformity of performance, while reducing miscommunication and failure to comply with industry regulations.
Ship of Opportunity (SOOP)	ICOS Ocean stations are based on instrumented Ships of Opportunity (SOOP) and Fixed Ocean Stations (FOS). The SOOP are either research vessels or commercial ships operating on regular, repeated ship routes

	on the European shelf and marginal seas and those of cargo vessels on open ocean routes.
Fixed Ocean Station (FOS)	ICOS Ocean stations are based on instrumented Ships of Opportunity (SOOP) and Fixed Ocean Stations (FOS). The FOS are fixed sites in the ocean. They are able to provide near-real-time data that also might contain information from greater depths, for example, about temperature anomalies.
Cooperation agreement	ICOS ERIC coordinates the National Networks and the Central Facilities via cooperation agreements. The agreements are negotiated with the NNs and the CFs.
ATC Metrology lab	The metrology lab is an ATC subunit, which is responsible for testing new sensors coming on the market and all instruments that are to be deployed into the ICOS network. In addition, they carry out a regular measurement technology survey, test, and analysis for advanced GHG instruments.
ATC Mobile lab	AT Mobile lab is a sub-unit of the Atmospheric Thematic Centre. The mobile lab visits stations to report and provide recommendations on station infrastructure, instruments, protocol implementation and use of calibration gases. It performs measurement in parallel for durations from 6 to 8 weeks. FMI (Finnish Meteorological Institute) is responsible for running and maintaining the Mobile lab.
ETC Test Unit	The Test Unit tests, evaluates and develops new sensors and new measurement methodologies. They provide technical assistance to ICOS Ecosystem sites, participate in working groups that write the measurement protocols with the scientific community and keep close contact with instrument manufacturers.
The Advanced Global Atmospheric Gases Experiment (AGAGE)	AGAGE is a global network of measuring stations on coastal or mountain sites around the world chosen primarily to provide accurate measurements of trace gases with lifetimes that are long compared to global atmospheric circulation times.
ICOS INWIRE	ICOS INWIRE is a project that developed new tools to improve European and global monitoring of greenhouse gas (GHG) concentrations and fluxes. It has enabled the provision of GHG data by merging new, in-situ GHG observations and surface remote sensing to validate satellite retrievals and data assimilation results.
ICOS Flask Sampler	Flask Sampler is a method for measuring air samples and it was developed by ICOS Flask and Calibration Laboratory (FCL, part of the ICOS CALs)
Total Carbon Column Observing Network (TCCON)	TCCON is a network of ground-based Fourier Transform Spectrometers recording direct solar spectra in the near-infrared spectral region. From these spectra, accurate and precise column-averaged abundance of CO_2, CH_4, N_2O, HF, CO, H_2O, and HDO are retrieved.
Light detection and ranging (LIDAR)	LIDAR is a method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor.

Saildrone Inc.	Saildrone Inc. is a company that ICOS OTC cooperates with. Saildrone Inc. has succeeded in making autonomic surface measurements in the most hazardous and less visited sea areas outside the most common commercial ship routes by circumnavigating the Southern Ocean.
AirCore	AirCore atmospheric sampling system is used to preserve a profile of the gas of interest from the middle stratosphere to the ground.
Picarro	Picarro is a measuring device used on ICOS Measuring Stations.
Personal Identifier (PID)	PID is 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.
Digital Object Identifier (DOI)	DOI is a persistent identifier used to identify objects uniquely, standardized by the International Organization for Standardization (ISO). DOIs are in wide use mainly to identify academic, professional, and government information, such as journal articles, research reports, data sets, and official publications.
Python	Python is a programming language. It currently ties with Java as the second most popular programming language in the world.
R	R is a programming language for statistical computing and graphics.
Fiscal discipline	Fiscal discipline refers to a state of an ideal balance between revenues and expenditure of government, in an economy. If the fiscal discipline is not maintained, then the government expenditure exceeds government receipts.
ICOS Preparatory Phase Projects (PPP)	The era of ICOS activities before ICOS ERIC is referred to as Preparatory Phase Projects.
Financial Committee (FC)	The Financial Committee is a working group of the General Assembly and reports directly to its Chair. The FC supports the cooperation between the GA, the Head Office, and the Director General. The support is especially related to budget presentations, financial reporting, communication in strategic decisions, and advising the GA chair on financial matters. In addition, the FC supports the financial strategy and sustainability of ICOS RI.
ICOS Science Conference	ICOS organizes the Science conference to ensure and sustain the highest quality of its science, to promote interdisciplinary and multidisciplinary science between scientists, policy- and decision-makers and other experts. It is organised every second year. The 2020 conference was organised online due to the COVID-19 restrictions.
In-kind contribution	In-kind contribution is a contribution of a good or a service other than money such as the use of laboratory services or green house space.
Norwegian Institute of Bioeconomy Research (NIBIO)	NIBIO delivers research, managerial support and knowledge for use in national preparedness, as well as for businesses and the society at large. It contributes to food security and safety, sustainable resource management, innovation and value creation through research and

	knowledge production within food, forestry and other biobased industries.
EOSCpilot	EOSCpilot is a virtual environment with open and seamless services for storage, management, analysis and re-use of research data, across borders and scientific disciplines by federating existing scientific data infrastructures, today scattered across disciplines and Member States.
EOSC Enhance	EOSC Enhance is a 24-month project funded by the European Commission and tasked with progressing the vision for the European Open Science Cloud (EOSC).
EOSC Future	EOSC Future is a project related to the European Open Science Cloud (EOSC) and it will run between 2021 - 2024.
Copernicus	Copernicus is the European Union's Earth Observation Programme that offers information services that draw from satellite Earth Observation and in-situ (non-space) data.
Drought Study, Drought Initiative	Drought Study is an ICOS lead research initiative. It included a set of studies showing how nature and crops in Europe respond to extremely dry conditions, such as occurred in the last three summers, 2018-2020. The results were published in Philosophical Transactions B.
ICOS Head Office (HO)	HO is a sub-unit to the ICOS ERIC, is responsible for coordinating the RI operations, administration, management and development of the RI as well as for communication.
ICOS ERIC	ICOS operations are coordinated by ICOS ERIC, which is a specific legal entity for European RIs created by the European Commission. ICOS ERIC consists of the Head Office, coordinating the RI operations, and the Carbon Portal, collecting and distributing ICOS data and derived products.
Jupyter notebooks	Jupyter notebook is an educational tool where e.g., ICOS data can be used. Jupyter is a Virtual Research Environment (VRE) incorporating a collection of tools for interactive computing and sharing of computational ideas.
Web of Science	Web of Science is a website that provides subscription-based access to multiple databases that provide comprehensive citation data for many different academic disciplines. It was originally produced by the Institute for Scientific Information (ISI) and is currently maintained by Clarivate Analytics.
Research Gate	Research Gate is a professional network for scientists and researchers. It can be used to share, and discuss research. Research Gate's mission is to connect the world of science and make research open to all.
Google Scholar	Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines.

Mendeley	Mendeley is a free reference manager and academic social network that helps its users to organize their research, collaborate with others online, and discover the latest research.
Clarivate	Clarivate is a company that owns and operates a collection of subscription-based services focused largely on analytics, including scientific and academic research, patent intelligence and compliance standards, pharmaceutical and biotech intelligence trademark, domain and brand protection. The services include Web of Science, Cortellis, Derwent, Derwent World Patents Index, CompuMark, MarkMonitor, Techstreet, Publons, EndNote, Kopernio, and ScholarOne.
European atmospheric transport inversion comparison project (EUROCOM)	The EUROCOM project aims at producing a collective assessment of the net carbon flux between the terrestrial ecosystems and the atmosphere in Europe for the period 2006–2015.
Inversion system	Atmospheric inversions are modelling tools commonly used for estimating large-scale (continental to regional) net sources and sinks of CO_2 and other stable atmospheric tracers from their observed concentrations.
Vendor exposition	Science conference also hosts vendor expositions that facilitate updates of latest research and developments from commercial manufacturers of technological tools.
Nationally Determined Contribution (NDC)	NDCs are the achievement of Paris Agreement. They are national long-term climate goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.
European Geosciences Union (EGU)	EGU is the leading organisation for Earth, planetary and space science research in Europe. It fosters fundamental geoscience research, alongside applied research that addresses key societal and environmental challenges. EGU vision is to realise a sustainable and just future for humanity and for the planet.

Abbreviations

ATC	ICOS Atmospheric Thematic Centre	Part of ICOS
BADM	Biological, Ancillary, Disturbance and Metadata (BADM)	International standard describing variables, units, and requirements for flux met data
BEERI	Board of European Environmental Research Infrastructures	Co-operation between RIs
BELSPO	Belgian Science Policy Office	Funds federal stations in Belgium
CAL	Central Analytical Laboratory	Part of ICOS
CAMS	Copernicus Atmosphere Monitoring Service	Provides data and information on atmospheric composition
CEOS	Committee on Earth Observation Satellites	Global satellite organization
CF	Central Facility	Body in ICOS organization
CHE	CO_2 Human Emissions	Horizon 2020 project 2018–2020
CI	Clumping Index	A research method presented in the ICOS Science Conference
CLASS	Climate Linked Atlantic Sector Science	CLASS is a five-year project funded by the Natural Environment Research Council in the UK.
CMEMS	Copernicus Marine Environment Monitoring Service	European organization
CoCO2	Copernicus carbon dioxide service	Horizon 2020 project 2021–2024
COOP+	Cooperation of Research Infrastructures to address global challenges in the environmental field	ICOS project 2016–2019
COVID-19	Corona virus disease 2019	
CP	Carbon Portal	Part of ICOS
CRL	ICOS Central Radiocarbon Laboratory	Part of ICOS
DGVM	Dynamic Global Vegetation Models	
DHP	Digital Hemispherical Photography	A research method presented in the ICOS Science Conference
DOI	Digital Object Identifier System	Applied on ICOS data
DSCOVR EPIC	Deep Space Climate Observatory Earth Polychromatic Imaging Camera	A NOAA Satellite instrument presented in the ICOS Science Conference
DWD	German Weather Service	
EAB	Ethical Advisory Board	Body of ICOS
EGU	European Geosciences Union	An international non-profit association; conference organizer
ENVRI	European Environmental Research Infrastructures	Co-operation between RIs
EOSC	European Open Science Cloud	
EOV	'Essential Ocean Variables' by Global Ocean Observing System (GOOS).	
ERIC	European Research Infrastructure Consortium	Term of European union

ETC	Ecosystem Thematic Centre	Part of ICOS
EUROCOM	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
FCL	ICOS Flask Calibration Laboratory	Part of ICOS
FLUXCOM	An Initiative to upscale biosphere-atmosphere fluxes from FLUXNET sites to continental and global scales	Lead by MPI in Germany
FLUXNET	1) The data portal and 2) measurement site network.	
FMI	Finnish Meteorological Institute	
FOE	The primary contribution of the Italian Ministry of Education, Universities and Research (MIUR) to fund the research activities conducted by public research bodies and institutes acting under the supervision of the Ministry	
FTIR	Fourier-transform infrared spectroscopy	
GA	General Assembly	Body of ICOS, representing member countries, (usually the ministries funding ICOS)
GAW	Global Atmosphere Watch	WMO activity
GCOS	Global Climate Observing System	UN activity
GCOS ECV	GCOS Essential Climate Variable	
GCP	Global Carbon Project	An important data user
GEMS	Global and regional Earth-system Monitoring using Satellite and in-situ data	EU project
GEO	Group on Earth Observations	Mainly a satellite organization
GEOCARBON	Operational Global Carbon Observing System	
GERI	Global Ecological Research Infrastructure	Co-operation between RIs
GHG	Green House Gases (CO_2, NH_4, N_3, water vapor)	
GOOS	Global Ocean Observing System	
GOBM	Global Ocean Biogeochemical	
GPP	Gross Primary Production	
H2020	Horizon 2020	EU Research and Innovation programme
ICOS	Integrated Carbon Observation System	
ICOS CP	Integrated Carbon Observation System Carbon Portal	Part of ICOS
ICOS ERIC	Integrated Carbon Observation System European Research Infrastructure Consortium.	

ICOS ETC	Integrated Carbon Observation System Ecosystem Thematic Centre	Part of ICOS
ICOS INWIRE		ICOS project
ICOS PPP	ICOS Preparatory Phase Projects	
ICOS RI	Integrated Carbon Observation System Research Infrastructure	
IG^{3}IS	Integrated Global Greenhouse Gas Information System	By WMO for implementation of Paris agreement
InGOS	Integrated Non-CO2 Observing System	ICOS project
JRC	The European Commission's Joint Research Centre	Treated as a member country in ICOS
KPI	Key Performance Indicator	
LIDAR	Light Detection and Ranging	A method for measuring distances by illuminating the target with laser light and measuring the reflection with a sensor.
LSCE	The French Laboratoire des Sciences du Climat et de l´Environnement (ATC host institution)	Host institute of ICOS ETC
MACC	Monitoring Atmospheric Composition and Climate	Pre-operational phase of Copernicus Atmosphere Service.
MACC-II	Monitoring Atmospheric Composition and Climate – Interim Implementation	Pre-operational phase of Copernicus Atmosphere Service.
MACC-III	The last of the pre-operational stages in the development of the Copernicus Atmosphere Service.	Pre-operational phase of Copernicus Atmosphere Service.
MATS	Marine Autonomy and Technology Showcase	Annual conference in UK
MDIR	Miljødirektoratet	The Norwegian Environment Agency
MEYS	The Czech Ministry of Education, Youth and Sports	
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	National Aeronautics and Space Administration (USA)	
NCAS	National Centre for Atmospheric Science (UK)	
NDC	Nationally Determined Contribution	According to the Paris Agreement
NDVI	Normalized Difference Vegetation Index	
NEE	Net Ecosystem Exchange	
NERC	Natural Environment Research Council (UK)	
NIBIO	Norwegian Institute of Bioeconomy Research	

NILU	Norwegian Institute for Air Research	
NFR	The Research Council of Norway	
NOAA	U.S. National Ocean and Atmosphere Administration	
NRT	Near-real-time	Describing data which is quickly available but only lightly processed
NWO	The Dutch Research Council	
ObsPack	Observation Package	Data delivery channel of NOAA in USA
OTC	Ocean Thematic Centre	Part of ICOS
PAP	Porcupine Abyssal Plain	An ICOS station in the UK
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.
POLDER	POLarization and Directionality of the Earth's Reflectance	A research method presented in the ICOS Science Conference
QA	Quality assurance	
QC	Quality control	
RI	Research Infrastructure	
RICOM	Research Infrastructure committee	Body of ICOS, representing all thematic centres, MSAs and Head office.
RINGO	Readiness of ICOS for Necessities of Integrated Global Observations	EU-funded project 2017–2020.
RISCAPE	European Research Infrastructures in the International Landscape	EU-funded project 2016–2019.
SAB	Scientific Advisory Board	Body of ICOS, representing external experts
SAG	Scientific Advisory Group	
SEACRIFOG	Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations	EU-funded project 2016–2019
SLP	Sea Level Pressure	ECV
SOCAT	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).
SOP	Standard Operation Procedure	

SSS	Sea Surface Salinity	ECV
SST	Sea Surface Temperature	ECV
TC	Thematic Centre	
TCCON	Total Carbon Column Observing Network	Link between ICOS and Satellite data. Potential integration to ICOS studied in RINGO.
ToR	Terms of Reference	
TRENDY	Trends in net land-atmosphere carbon exchange	Experiment in 1980–2010
UEA	University of East Anglia	
UKCEH	UK Centre for Ecology & Hydrology	
UNFCCC	United Nations Framework Convention on Climate Change	United Nations body
VERIFY	Observation-based system for monitoring and verification of greenhouse gases	Horizon 2020 project 2018–2021
WDCGG	World Data Centre for Greenhouse Gases	
WMO	World Meteorological Organization	United Nations body