Ref. Ares(2019)6423841 - 17/10/2019

D12.1
Relation between Grand Challenges and environmental RIs including the module of the ENVRI Reference Model

WORK PACKAGE 12 – A Framework for Environmental Literacy

LEADING BENEFICIARY: ENVIRONMENT AGENCY AUTRIA (EAA)

Authors:	Beneficiary/Institution
Michael Mirtl	EAA
Gisela Pröll	EAA
Florian Haslinger	ETH
Barbara Magagna	EAA
Regis Kalaydjian	IFREMER

Accepted by: Florian Haslinger (WP 12 leader)

Deliverable type: REPORT

Dissemination level: PUBLIC

Deliverable due date: 1.2.2019/M45

Actual Date of Submission: 8.10.2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654182

ABSTRACT

The European environmental Research Infrastructures serve a wide range of Grand Challenges. Our study assessed the overall response of the environmental RIs as represented in the ENVRIplus H2020 InfraDev cluster project of European environmental infrastructures to three major Grand Challenge classifications (European Commission societal Grand Challenges (EC), US National Research Council environmental research Grand Challenges (NRC), International Council for Science Grand Challenges in the scientific workflow (ICSU)). Based on this ENVRIplus Grand Challenges matrix, we systematically identified the scope of all RIs, enabling consistent comparisons between individual RIs and between the ENVRIplus domains (atmosphere, biosphere, lithosphere, hydrosphere).

Across domains the ENVRIplus RIs most strongly respond to the following Grand Challenges (means of weighted response of all RIs in %):

- EC Observation (70%)
- EC Resource-management (60%)
- NRC Biogeochemistry (57%)
- NRC Biodiversity (57%)
- NRC Climate (58%)

Concerning the ICSU workflow, the focus consistently lies on "observing" and "forecasting". "Confining", "responding" and "innovating" are of varying relevance across RIs.

RIs with a unique role became clearly visible (e.g. the security aspect of EPOS). The assessment also reflects major similarities and differences between pairs of RIs with basically similar scope (e.g. ICOS vs. ACTRIS, eLTER vs. AnaEE).

The structure of the ENVRIplus Grand Challenges matrix was used for designing an additional module of the ENVRI Reference Module, enhancing the characterization of RIs as part of the "Science viewpoint" for consistent metadata provisioning on the Grand Challenges relevance of RIs in the future.

Project internal reviewer(s):

Project internal reviewer(s):	Beneficiary/Institution
Ari Asmi	University of Helsinki
Werner L. Kutsch	ICOS ERIC

Document history:

Date	Version
v03, April 2019	Draft for comments by WP lead
v07, July 2019	Corrected version
V14, 8.10.2019	Submitted by W.L. Kutsch (ICOS ERIC)

DOCUMENT AMENDMENT PROCEDURE

Amendments, comments and suggestions should be sent to the authors (Mirtl Michael, EAA)

TERMINOLOGY

A complete project glossary is provided online here:
https://wiki.envri.eu/pages/viewpage.action?pageId=14452608

PROJECT SUMMARY

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. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

Table of Contents

Relation between Grand Challenges and environmental RIs inclunding the module of the ENVRIplus Reference Model

1 Abstract

The European environmental Research Infrastructures serve a wide range of Grand Challenges. Our study assessed the overall response of the environmental RIs as represented in the ENVRIplus H2020 InfraDev cluster project of European environmental infrastructures to three major Grand Challenge classifications (European Commission societal Grand Challenges (EC), US National Research Council environmental research Grand Challenges (NRC), International Council for Science Grand Challenges in the scientific workflow (ICSU)). Based on this ENVRIplus Grand Challenges matrix, we systematically identified the scope of all RIs, enabling consistent comparisons between individual RIs and between the ENVRIplus domains (atmosphere, biosphere, lithosphere, hydrosphere).

Across domains the ENVRIplus RIs most strongly respond to the following Grand Challenges (means of weighted response of all RIs in %):

EC Observation (70%)

EC Resource-management (60%)

NRC Biogeochemistry (57%)

NRC Biodiversity (57%)

NRC Climate (58%)

Concerning the ICSU workflow, the focus consistently lies on “observing” and “forecasting”. “Confining”, “responding” and “innovating” are of varying relevance across RIs.

RIs with a unique role became clearly visible (e.g. the security aspect of EPOS). The assessment also reflects major similarities and differences between pairs of RIs with basically similar scope (e.g. ICOS vs. ACTRIS, eLTER vs. AnaEE).

The structure of the ENVRIplus Grand Challenges matrix was used for designing an additional module of the ENVRI Reference Module, enhancing the characterization of RIs as part of the “Science viewpoint” for consistent metadata provisioning on the Grand Challenges relevance of RIs in the future.

2 Motivation and relation to the Work Programme

Research collectively supported by environmental RIs investigates interaction and dependencies between the (human) society and the (natural) environment. It ultimately aims at increasing Environmental Literacy (E.L.) of society, which *“…is the capability of an assembly of subunits of a society to jointly generate appropriate knowledge, proper strategies, and reasonable adaptations to changing environmental conditions and adequately anticipate unwanted effects of human actions on the environment. To achieve this capability, societies usually create textures of institutions, organizations, social subgroups, activities, and regulatory mechanisms to sustain themselves. One key concept is the informed feedback in the human / societal decision making process, that is the ability to assess and understand the environmental impact of human action, and to utilize this understanding in taking decisions on future actions - the ‘Human-Environment System’ (HES) framework” (Scholz 2011).*

Applied to Research Infrastructures in the environmental domain, the concept of Environmental Literacy allows to develop a framework that RIs and their actors can use to define their specific role in this informed feedback loop, assess their capacity to meet the Grand Challenges, formulate goals, and evaluate their performance. eLTER (represented through the Environment Agency Austria) had a leading role in elaborating a scheme to identify the relevance of RIs for current Grand Challenges (GCs) and provide comparable profiles of RIs in terms of their focal GCs.

3 Method

3.1 Selection of Grand Challenge classifications

Grand Challenges embody by definition formalized high-level indicators for needs in terms of substantive problems, which require strong commitments and long-term collaborative efforts to be solved. ENVRIplus chose the RIs response to Grand Challenges to demonstrate environmental RIs role at the science-society-policy interface. Dozens of GC classifications have emerged across realms like engineering, government and military, medicine and health, science and technology.

A key question in the endeavor of Task 12.1 was, if ENVRIplus should develop a customized system of Grand Challenges, i.e. yet another GC classification, or rather rely on existing GC classifications (e.g. ICSU Grand Challenges or EC Grand Challenges). Each option features a number of advantages and shortcomings. The clear advantage was that a new compilation would suit the actual environmental RI scopes better than classifications elaborated for other purposes, whereas the usage of existing GC classifications allowed for a better comparability and linkage of findings with other processes, strategy building and stakeholders referring to the same GC classifications.

The WP 12 team of ENVRIplus decided for the latter and more time demanding choice, which required an assessment and prioritization of the most suited GC classification systems.

Step 1: EAA, together with ETHZ and UHEL undertook an initial review of various published 'Grand Challenges' classifications (step 1), to understand their potential relevance as guidance for the work ahead. The following classifications were chosen:

- European Commission's Societal Challenges for Europe 2020 (http://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges)
- ICSU Earth System Science for Global Sustainability: The Grand Challenges. (http://www.icsu.org/news-centre/press-releases/2010/scientific-grand-challenges-identified-to-address-global-sustainability)
- US Natl. Research Council Grand Challenges in Environmental Sciences (http://www.nap.edu/catalog/9975/grand-challenges-in-environmental-sciences)
- ESFRI Grand Research Challenges used for the 2014 ESFRI environmental RI interoperability and landscape analysis (Asmi et al. 2014)

For details see Chapter 3.2.

In the second step, all RIs involved in ENVRIplus were asked to indicate to what extent the individual Grand Challenges in each of the four GC systems were useful to reflected their scope and targets (from 0-10). Herein the challenge was to cope with the RIs trained tendency to underpin their own relevance rather than examining the usability of a classification system. Several rounds of bilateral discussions and clarifications followed the consortium exercise carried out at the ENVRIplus meeting 2015 in Helsinki (see).

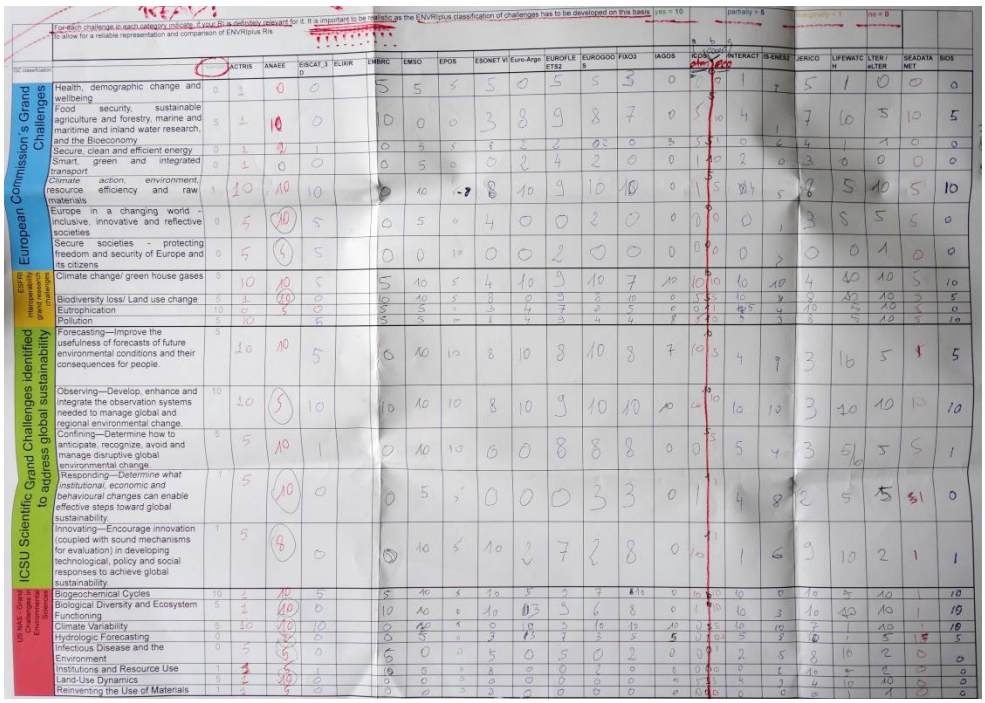


Figure 1: Usability assessment of existing Grand Challenge classifications, executed at the ENVRIplus meeting in Helsinki in 2015. Colored blocks of rows: GCs in 4 classifications; columns: RIs; ranking from 0 (not reflecting scope) to 10 (fully reflecting scope).

From this survey, the most relevant challenges from the various systems were selected and further analyzed. This revealed, that the ESFRI challenges were redundant, and that the ICSU GC classification reflects a 'workflow' view, while EC and US-NRC challenges are 'topical', with a more societal/political focus for the EC Grand Challenges and a stronger research/development aspect for the US-NRC classification.

3.2 Selected Grand Challenge classifications

3.2.1 European Commission's Grand Societal Challenges (GSC)

3.2.1.1 Brief description

Currently Europe has to face critical societal and political concerns such as climate change, the ageing population and energy security. The overall target of the Grand Societal Challenges of the European Commission (GSC) is to find novel solutions on how to overcome these concerns and on how to shape Europe's future towards a sustainable common future. The European Commission has identified a series of Grand Societal Challenges where targeted investments should directly result in major benefits for Europe's society. The seven Grand Challenges are (i) health and wellbeing (ii) food security (iii) energy (iv) transport (v) climate action (vi) society and (vii) security. The Grand Societal Challenges approach is widely referred to in European policy-making and is an established topic in Europe's research area (ERA) (European Commission 2010, McGrath et al. 2014) and one of the three priorities of Europe's largest research funding programme Horizon 2020, the Framework Programme for Research and Innovation. A significant part of this research programme, i.e. 31 billion Euros, is invested in solving the big societal challenges. A key issue for environmental science and research is to find answers to complex questions that emerge from the grand challenges humanity is facing such as climate change, biodiversity loss and food security.

3.2.1.2 History

The Grand Societal Challenges approach has emerged from a Green Paper (European Commission 2007) with its aim to discuss the future orientations of ERA - the key reference for research policy in Europe. Major outcomes of this Green Paper comprised six so-called ERA dimensions which define important issues for ERA and solution-focused ways on how to create benefits of ERA to Europe's citizens and political leaders: (i) an adequate flow of competent researchers (ii) world-class research infrastructures (iii) excellent research institutions (iv) effective knowledge sharing (v) well-coordinated research programmes and priorities (vi) a wide opening of the European

Research Area to the world. Finally, the GSCs for a sustainable common future of Europe were formulated from the Bureau of European Policy Advisors of the European Commission (BEPA), with contributions from the Joint Research Centre-Institute for Prospective Technological Studies (JRC-IPTS) and several other institutes. The main target was to analyze the 'main trends ahead and possible disruptive global challenges in the future and to examine how the EU could position itself to take an active role in shaping a response to them', adapting to situations before they occur and, crucially, to be able to 'shape the future' (Boden et al. 2010).

3.2.1.3 Definitions & aims

The seven Grand Societal Challenges of the European Commission and its main aims are described according to the Horizon 2020 webpage (see http://ec.europa.eu/programmes/Horizon 2020/en/h2020-section/societal-challenges):

Health, demographic change and wellbeing

- This GSC generally aims to secure health and human well-being for all. This includes the improvement of our understanding of the processes and mechanisms underlying health, healthy and independent ageing and disease. This GSC aims at contributing to the development of new, safer and more effective tools and models for continued improvements in the quality and sustainability of healthcare delivery, prevention, and monitoring health.

Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy

- This GSC mainly addresses food and feed security and safety for all. Activities of this GSC aim at promoting a transition towards an optimal and renewable use of natural resources and towards sustainable primary production and processing systems. There is an urgent need for innovation of these systems to produce more food, fiber and other bio-based products with minimized inputs, environmental impact and greenhouse gas emissions. These innovations should enhance the long-term maintenance of ecosystem services with significant socio-economic benefits for Europe.

Secure, clean and efficient energy

- Activities of this GSC aim at accelerating a transition towards a reliable, sustainable and competitive energy system and to ensure access to a low-cost, reliable, sustainable and modern energy for all. A key issue of this GSC is to find innovative solutions to limited resources, growing energy needs and climate change. Main objectives comprise a reduction of the energy consumption and carbon footprint, a cheap and low-carbon electricity supply, alternative fuels and mobile energy sources, new knowledge and innovative technologies, etc.

Smart, green and integrated transport

- The major aim of this GSC is to improve the competitiveness of the European transport industries and achieve a transport system across Europe which is resource-efficient, climate-and-environmentally-friendly, safe and seamless for the benefit of all citizens, the economy and society.

Climate action, environment, resource efficiency and raw materials

- This GSC focuses on mitigating climate change impacts as well as developing and improving measures on climate change adaption. Generally, activities of this GSC will foster the environmental protection and integrity, the sustainable management of natural resources, biodiversity and ecosystems which in turn should enhance the resilience of ecosystems, economy and society. A key issue of this GSC is to find answers on how to overcome the growing demand for limited natural resources and raw materials and finding new ways of using these essential resources and materials in a more sustainable manner.

Europe in a changing world – inclusive, innovative and reflective societies

- This challenge is about undertaking R&I activities needed to reduce Europe's huge societal challenges concerning inequality, social exclusion, poverty and unemployment. About 80 million people are at risk of poverty and 14 million young people are not in education, employment or training. There is an urgent need to overcome the economic crisis and unemployment, particularly among young people.

Secure societies – protecting freedom and security of Europe and its citizens

- This GSC aims at protecting the society against natural and anthropogenic disasters, fighting crime and terrorism, improving border security, and providing enhanced cyber-security. Activities and objectives range from developing new crisis management tools to communication interoperability, new solutions for the protection of critical infrastructure, new forensic tools to protection against explosives, etc.
-

3.2.2 US National Research Council Grand Challenges in Environmental Sciences

(http://www.nap.edu/catalog/9975/grand-challenges-in-environmental-sciences)

3.2.2.1 Brief description

Rapid increases in the human population and economic activities threaten environmental systems at multiple scales. Habitat degradation, ozone pollution, accelerated rates of species extinction and changes in water and nutrient cycles are among the major concerns of today's society. The Environmental Grand Challenges' initiative by the National Research Council (NRC) addresses the most important and challenging scientific questions in environmental sciences that urgently have to be solved for the next generation. To sum up, eight GCs were identified namely (i) biogeochemical cycles (ii) biological diversity and ecosystem functioning (iii) climate variability (iv) hydrological forecasting (v) infectious disease and the environment (vi) institutions and resource use (vii) land-use dynamics and (viii) reinventing the use of materials. In order to broaden environmental knowledge and to save the environment for the next generation, environmental changes and threats to environmental systems need to be detected before they occur. Even if there is a need to pursue all eight GCs for this purpose, four priority GCs (ii, iv, v, vii) were defined and recommended as immediate research investment by the National Science Foundation (NSF) and others (see e.g. https://www.nsf.gov/awardsearch).

3.2.2.2 History

The National Science Foundation (NSF), together with the National Research Council (NRC) established a Committee on Grand Challenges in Environmental Sciences, with a total of 17 members which cover a broad range of disciplines to define the greatest potential for investment in science, i.e. defining grand challenges in environmental science. After more than 200 nominations from the scientific community, the Committee on Grand Challenges selected the most forceful eight GCS and its recommendations during five meetings in the year 1999 with contributions from many experts. The selection criteria for the 8 GCs included a significant scientific and practical outcome, large scope, relevance to important environmental issues, feasibility, timeliness, and requirement for multidisciplinary collaboration.

3.2.2.3 Definitions & aims

The eight GC are described according to the executive summary of the report http://www.nap.edu/catalog/9975/grand-challenges-in-environmental-sciences.

Biogeochemical Cycles

- The challenge is to get a better insight into the Earth's major biogeochemical cycles, evaluate the influence of human activities on biogeochemical processes, and determine how to keep the biogeochemical processes balanced. Priority research areas include quantifying the sources and sinks of nutrient elements and gaining a better overview of the biological, chemical, and physical processes regulating transformations among them. There is a need to improve our understanding of the interactions between the different biogeochemical cycles and to assess anthropogenic perturbations of biogeochemical cycles and their impacts on ecosystem functioning, atmospheric chemistry, and human activities. Activities in this GC should provide a scientific basis for decision making by exploring techniques and institutional approaches on how to manage biogeochemical cycles and anthropogenic perturbations.

Biological Diversity and Ecosystem Functioning

- There is an alarming gap in our current understanding of the role of biodiversity in context with ecosystem functioning. This challenge highlights the critical need for an improved understanding of the factors affecting biological diversity and ecosystem structure and functioning, considering also human impact. Activities of this GC should focus on developing tools for a rapid assessment of biodiversity at multiple scales and on predicting the diversity of biomes, growth forms, and functional types, as well as species and genotypes at different spatial and temporal scales. This GC should focus on developing a theory for the role of biodiversity in terms of ecosystem functioning and on investigating habitats that can sustain biological diversity together with people and their activities.

Climate Variability

- The challenge is to increase our ability to predict climatic variations, which range from extreme events to decadal time scales in the future. One challenge may comprise to assess realistically the resulting impacts on ecosystems and human life. Important research areas include improving observational capability, extending the record of observations back into the Earth's history, improving diagnostic process studies, developing increasingly comprehensive models, and conducting integrated impact assessments that take human responses and impacts into account.

Hydrologic Forecasting

- The challenge is to develop an improved understanding of and ability to predict changes in freshwater resources and the environment caused by floods, droughts, sedimentation, and contamination. Important research areas include improving understanding of hydrologic responses to precipitation, surface water generation and transport, environmental stresses on aquatic ecosystems, the relationships between landscape changes and sediment fluxes, and subsurface transport, as well as mapping groundwater recharge and discharge vulnerability.

Infectious Disease and the Environment

- This challenge focuses on a better understanding of the ecological and evolutionary aspects of infectious diseases and the interactions among pathogens, hosts/receptors, and the environment. In turn, this should enhance the prevention with regard to the infectivity and virulence of organisms that threaten plant, animal, and human health at the population level. Important research areas include (i) examining the effects of environmental changes as selection agents on pathogen virulence and host resistance, (ii) exploring the impacts of environmental change on disease etiology, vectors, and toxic organisms, (iii) developing new approaches to surveillance and monitoring, and (iv) improving theoretical models of host-pathogen ecology.

Institutions and Resource Use

- The challenge is to understand how human use of natural resources is shaped by institutions such as markets, governments, international treaties, and formal and informal sets of rules that are established to govern resource extraction, waste disposal, and other environmentally important activities. Important research areas include (i) documenting the institutions governing critical lands, resources, and environments; (ii) identifying the performance attributes of the full range of institutions governing resources and environments worldwide, from local to global levels; (iii) improving understanding of change in resource institutions; and (iv) conceptualizing and assessing the effects of institutions for managing global commons.

Land-Use Dynamics

- The challenge is to develop a systematic understanding of changes in land uses and land covers that are critical to ecosystem functioning and services and human welfare. Important research areas include (i) developing long-term, regional databases for land uses, land covers, and related social information; (ii) developing spatially explicit and multisectoral land-change theory; (iii) linking land-use change theory to space-based imagery; and (iv) developing innovative applications of dynamic spatial simulation techniques.

Reinventing the Use of Materials

- This challenge aims at improving the quantitative understanding of the global budgets and cycles of materials widely used by humanity and how the life cycles of these materials (their history from the raw-material stage through recycling or disposal) may be modified. Important research areas include (i) developing spatially explicit budgets for selected key materials; (ii) developing methods for more complete cycling of technological materials; (iii) determining how best to utilize materials that have uniquely useful industrial applications but are potentially hazardous to the environment; (iv) developing an understanding of the patterns and driving forces of human consumption of resources; and (v) developing models for possible global scenarios of future industrial development and associated environmental implications.
-

3.2.3 ICSU Earth System Science for Global Sustainability: The Grand Challenges

https://www.icsu.org/publications/earth-system-science-for-global-sustainability-the-grand-challenges

3.2.3.1 Brief description

Human societies and human well-being are increasingly facing dangerous threats resulting from global change. There is an urgent need for the international scientific community to develop the knowledge that can inform and shape effective responses to these threats in ways that facilitate progress toward the sustainable development goals (SDGs). The International Council for Science (ICSU) together with the International Social Science Council (ISSC) and other partners intended to mobilize the international global change scientific community, which plays a central role in understanding the functioning of the Earth system and the human impacts on that system, towards research in a way that supports sustainable development in the context of global change. The goal of changing priority topics in Earth System Science towards global sustainability requires a focus on new research priorities and on new ways of doing and using research to address needs at global, regional, national, and local scales. An international consultative process led by ICSU and its partners was designed to: (a) identify broadly-accepted grand challenges in Earth system science for global sustainability; (b) identify high priority research that must be carried out to address those challenges; and (c) mobilize scholars in the sciences (social, natural, health, and engineering) and humanities to pursue that research. The five Grand Challenges are (i) *Forecasting*—Improve

the usefulness of forecasts of future environmental conditions and their consequences for people; (ii) *Observing*—Develop, enhance and integrate the observation systems needed to manage global and regional environmental change; (iii) *Confining*—Determine how to anticipate, recognize, avoid and manage disruptive global environmental change; (iv) *Responding*—Determine what institutional, economic and behavioral changes can enable effective steps toward global sustainability (v) *Innovating*—Encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability.

3.2.3.2 History

In 2009, the International Council for Science (ICSU) and the International Social Science Council (ISSC) carried out an internet consultation in order to define the focus and framework of Earth system research for the coming decade. During the process, future research priorities for Earth system science and the so-called five Grand Challenges were defined to address global sustainability. Each GC meets four criteria: (i) scientific importance, (ii) need for global coordination, (iii) relevance to decision-makers, and (iv) leverage (i.e., would help address multiple problems). For each grand challenge, several important research questions were identified as answerable within a decade. The internet consultation resulted in about 300 proposals of new Earth system research priorities contributed by colleagues from 85 countries. These proposed research priorities provided the basis for a workshop in September 2009 involving senior researchers, early career scientists, science-policy experts and representatives of research funding agencies. The workshop resulted in a draft document with numerous selection criteria, the grand challenges and its research priorities. After a review between December 2009 and March 2010 with comments from 46 institutions and over 200 individuals the consultative process was closed.

3.2.3.3 Definitions & aims

Observing

- Activities in this GC aim at developing, enhancing and integrating the observation systems that are needed to manage global and regional environmental change. A key issue of this challenge is to find answers to the following questions:
  - What do we need to observe in coupled social-environmental systems, and at what scales, in order to respond to, adapt to, and influence global change?
  - What are the characteristics of an adequate system for observing and communicating this information?

Forecasting

- This GC aims at improving forecasts of future environmental conditions and their consequences for people. Priority research questions comprise:
  - What significant environmental changes are likely to result from human actions? How would those changes affect human well-being, and how are people likely to respond?
  - What threats do global environmental changes pose for vulnerable communities and groups and what responses could be most effective in reducing harm to those communities?

Confining

- This GC aims at determining how to anticipate, recognize, avoid and manage disruptive global environmental change and to find answers to the following questions:
  - Which aspects of the coupled social-environmental system pose significant risks of positive feedback with harmful consequences?
  - How can we identify, analyze and track our proximity to thresholds and discontinuities in coupled social-environmental systems? When can thresholds not be determined?
  - What strategies for avoidance, adaptation and transformation are effective for coping with abrupt changes, including massive cascading environmental shocks?
  - How can improved scientific knowledge of the risks of global change and options for response most effectively catalyze and support appropriate actions by citizens and decision-makers?

Responding

- The challenge of this GC is to determine what institutional, economic and behavioral changes can enable effective steps toward global sustainability. The following research questions arise:
  - What institutions and organizational structures are effective in balancing the trade-offs inherent in social-environmental systems at and across local, regional and global scales and how can they be achieved?
  - What changes in economic systems would contribute most to improving global sustainability, in the context of global environmental change, and how could they be achieved?

- What changes in behavior or lifestyle, if adopted by multiple societies, would contribute most to improving global sustainability, in the context of global environmental change, and how could they be achieved?
- How can institutional arrangements prioritize and mobilize resources to alleviate poverty, address social injustice and meet development needs under rapidly changing and diverse local environmental conditions and growing pressures on the global environment?
- How can the need to curb global environmental change be integrated with the demands of other inter-connected global policy challenges, particularly those related to poverty, conflict, justice and human security?
- How can effective, legitimate, accountable and just, collective environmental solutions be mobilized at multiple scales? What is needed to catalyze the adoption of appropriate institutional, economic or behavioral changes?

Innovating

- This GC focuses on encouraging innovation (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability. A key issue of this challenge is to find answers to the following questions:
  - What incentives are needed to strengthen systems for technology, policy and institutional innovation to respond to global environmental change and what good models exist?
  - How can pressing needs for innovation and evaluation be met in the following key sectors?
  - How can global energy security be provided entirely by sources that are renewable and that have neutral impacts on other aspects of global sustainability, and in what time frame?
  - How can competing demands for scarce land and water be met over the next half century while dramatically reducing land-use greenhouse gas emissions, protecting biodiversity, and maintaining or enhancing other ecosystem services?
  - How can ecosystem services meet the needs for improving the lives of the world's poorest peoples and those of developing regions (such as safe drinking water and waste disposal, food security and increased energy use) within a framework of global sustainability?
  - What changes in communication patterns are needed to increase feedback and learning processes to increase the capacity of citizens and officials, as well as to provide rapid and effective feedback to scientists regarding the applicability and reliability of broad findings and theoretical insights to what is observed in the field?
  - What are the potentials and risks of geo-engineering strategies to address climate change, and what local to global institutional arrangements would be needed to oversee them, if implemented?

3.3 Condensing a priority set of GCs from selected GC classifications

The number of Grand Challenges used by Task 12.1 needed to be kept in a range suited to be answered in a survey, which could be entirely filled in about 1 hour. Secondly, the Grand Challenges should be defined in a few sentences to avoid exhaustive reading by the respondents.

In order to keep the ENVRIplus GC matrix manageable, the target was to select about eight Grand Challenges from each the EC and US-NRC classifications according to their principal relevance across environmental RIs.

The Grand Challenges contained in the NRC and ICSU classifications represent both a feasible number of GCs, and level of specification and detail.

Contrary to that, the EC Grand Societal Challenges (EC GSC, short: EC) represented at the time of retrieval from the WWW a complex hierarchical system (partly heterogeneous across individual GCs) from the actual GCs to objectives, aims and subaims (partly targets). Several of the high level GCs were by definition entirely out of scope for environmental RIs at all (e.g. technical aspects of energy and transport, military aspects of security). However, as for the relevant high level GCs numerous redundancies further expanded the overall list at the level of objectives and below. In order to achieve a workable number of GCs, the team of Task 12.1 carried out an internal selection, ranking and prioritization exercise starting from the consolidated collation shown in Table 1.

Table 1: Collation of EC Grand Societal Challenges with sub-topics as basis for selection

Grand Societal Challenge	Sub-topic [O: objective; A: aim]
Health, demographic change and wellbeing;	
Health	improve our understanding of the causes and mechanisms underlying health, healthy ageing and disease;
Health	improve our ability to monitor health and to prevent, detect, treat and manage disease;
Health	support older persons to remain active and healthy;
Health	and test and demonstrate new models and tools for health and care delivery.
Health	
Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy;	
Food security	Food security
Food security	sustainable agriculture
Food security	Forestry, marine and maritime and inland water research
Food security	Bioeconomy
Food security	
Secure, clean and efficient energy;	
Energy	Reducing energy consumption and carbon footprint
Energy	Low-cost, low-carbon electricity supply
Energy	Alternative fuels and mobile energy sources
Energy	A single, smart European electricity grid
Energy	New knowledge and technologies
Energy	Robust decision making and public engagement
Energy	Market uptake of energy and ICT innovation.
Energy	
Smart, green and integrated transport;	
Transport	Mobility for Growth
Transport	Green Vehicles
Transport	Small Business and Fast Track Innovation for Transport
Transport	
Climate action, environment, resource efficiency and raw materials;	
Climate and ressource efficiency	O: to achieve a resource – and water - efficient and climate change resilient economy and society,
Climate and ressource efficiency	O: the protection and sustainable management of natural resources and ecosystems
Climate and ressource efficiency	Objective: a sustainable supply and use of raw materials, in order to meet the needs of a growing global population within the sustainable limits of the planet's natural resources and eco-systems.
Climate and ressource efficiency	A: Fighting and adapting to climate change
Climate and ressource efficiency	A: Protecting the environment, sustainably managing natural resources, water, biodiversity and ecosystems
Climate and ressource efficiency	Activity: Ensuring the sustainable supply of non-energy and non-agricultural raw materials
Climate and ressource efficiency	Activity: Enabling the transition towards a green economy and society through eco-innovation
Climate and ressource efficiency	A: Developing comprehensive and sustained global environmental observation and information systems
Climate and ressource efficiency	Activity: Cultural heritage
Climate and ressource efficiency	
Europe in a changing world - inclusive, innovative and reflective societies;	
Scieties	New ideas, strategies and governance structures for overcoming the crisis in Europe (resilient economic and monetary Union, EU growth agenda, EU social policies, the future of European integration, emerging technologies in the public sector).
Scieties	The young generation in an innovative, inclusive and sustainable Europe (job insecurity, youth mobility, adult education, social and political engagement of young people, modernisation of public administrations).
Scieties	Reflective societies: transmission of European cultural heritage, uses of the past, 3D modelling for accessing EU cultural assets.
Scieties	Europe as a global actor: focusing research and innovation cooperation with third countries, new geopolitical order in the Mediterranean, EU eastern partnership and other third countries.
Scieties	New forms of innovation in the public sector, open government, business model innovation, social innovation community, ICT for learning and inclusion.
Secure societies - protecting freedom and security of Europe and its citizens.	
Security	Enhance the resilience of our society against natural and man-made disasters, ranging from the development of new crisis management tools to communication interoperability, and to develop novel solutions for the protection of critical infrastructure;
Security	to fight crime and terrorism ranging from new forensic tools to protection against explosives;
Security	to improve border security, ranging from improved maritime border protection to supply chain security and to support the Union's external security policies including through conflict prevention and peace building;
Security	and to provide enhanced cyber-security, ranging from secure information sharing to new assurance models.

The resulting list of 9 GCs contained redundant entries for "Protecting the environment, sustainably managing natural resources, water, biodiversity and ecosystems", which occur in several branches of the EC GSC hierarchy in the high level Climate GC (see Table 2).

Table 2: List of EC Grand Societal Challenges with sub-topics as basis for selection

Grand Societal Challenge	Sub-topic [O: objective; A: aim]
Health, demographic change and wellbeing;	
Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy;	
Food security	Food security
Food security	Forestry, marine and maritime and inland water research
Secure, clean and efficient energy;	
Energy	New knowledge and technologies
Smart, green and integrated transport;	
Climate action, environment, resource efficiency and raw materials;	
Climate and ressource efficiency	O: to achieve a resource – and water - efficient and climate change resilient economy and society,
Climate and ressource efficiency	O: the protection and sustainable management of natural resources and ecosystems
Climate and ressource efficiency	A: Fighting and adapting to climate change
Climate and ressource efficiency	A: Protecting the environment, sustainably managing natural resources, water, biodiversity and ecosystems
Climate and ressource efficiency	A: Developing comprehensive and sustained global environmental observation and information systems
Europe in a changing world - inclusive, innovative and reflective societies;	
Secure societies - protecting freedom and security of Europe and its citizens.	
Security	Enhance the resilience of our society against natural and man-made disasters, ranging from the development of new crisis management tools to communication interoperability, and to develop novel solutions for the protection of critical infrastructure;

The resulting list of Grand Challenges was numbered as follows for fast referencing in all graphs, tables and texts of this report:

The International Council for Science (ICSU) Grand Challenges:

- ICSU1 Observing: Develop, enhance, and integrate observation systems to manage global and regional environmental change
- ICSU2 Forecasting: Improve the usefulness of forecasts of future environmental conditions and their consequences for people
- ICSU3 Confining: Determine how to anticipate, avoid and manage disruptive global change
- ICSU4 Responding: Determine institutional, economic, and behavioral changes to enable effective steps toward global sustainability
- ICSU5 Innovating: Encourage innovation (and mechanisms for evaluation) in technological, policy, and social responses to achieve global sustainability

Selected EC Grand Societal Challenges

- EC1 Food security: agro
- EC2 Food security: non-agro habitats & water
- EC3 Energy: New knowledge and technologies
- EC4 Climate: Resource and water efficient and CC resilient economy and society
- EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
- EC6 Climate: Fighting and adapting to CC
- EC7 Climate: Develop global environm. observation and information systems
- EC8 Security: Enhance the resilience of society against natural and man-made disasters

US National Research Council Grand Challenges for Environmental Research

- NRC1 Biogeochemical Cycles
- NRC2 Biological Diversity and Ecosystem Functioning
- NRC3 Climate Variability
- NRC4 Hydrologic Forecasting

- NRC5 Infectious Disease and the Environment
- NRC6 Institutions and Resource Use
- NRC7 Land-Use Dynamics
- NRC8 Reinventing the Use of Materials (due to marginal relevance skipped in several graphs and tables)

3.4 ENVRIplus GC Matrix

Instead of using the selected GCs as a plain list for cross-checking the RIs response to them, the ENVRIplus matrix framework was developed. The novelty is, that it **crosswise** overlays **topical challenge aspects** like climate change for food security (EC, US-NRC) with the **workflow view** (Figure 12.1.1). The matrix now allows checking (at the RI level) relevance not only regarding a specific topic/challenge, but also where in the scientific and societal process chain the RI is engaged, distinguishing according to the ICSU scheme between observing, forecasting, confining, responding and innovating.

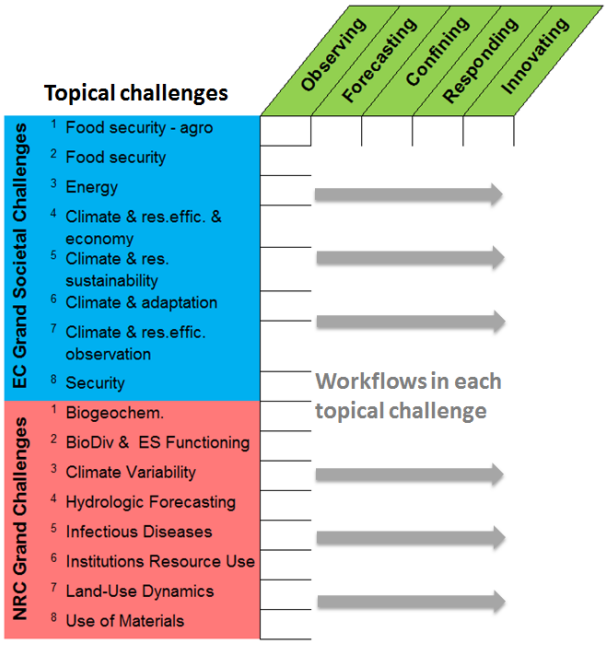


Figure 2: Integrated matrix framework of Grand Challenges classification systems combining topics of challenges (EC for the societal focus and US-NRC for the science focus) with the scientific, technical and societal ICSU workflow from observation to forecasting, confining, responding and innovation.

3.5 Online survey, data quality and resulting measures

The ENVRIplus GC matrix served as backbone for casting an online survey (tool: SurveyMonkey). Persons representing the participating RIs were asked to indicate their RIs respective profile concerning the relevance of the RI scope for responding to Grand Challenges. This was performed at three granularity levels:

- Level 1: A fast indication (yes/no) if the RI was involved in any of the ICSU workflow steps concerning a given GC (yes/no);
- Level 2: A more detailed answer to the same question distinguishing between four levels of relevance (not at all; marginally; partly; fully)
- Level 3: Detailed textual explanations of the two main Grand Challenges (EC or NRC) a given RI contributes to, including indication of the main services related to this contribution.
-

The survey was first put online in early 2016 for testing. The data collection was slow and despite of numerous reminders by the Task-, WP- and project lead lasted till late 2017. 69 persons responded to the survey.

3.5.1 Survey metadata

Names, institutional affiliation and email addresses were filled by 100%. Other main metadata of the survey are provided in Figure 3 to Figure 6.

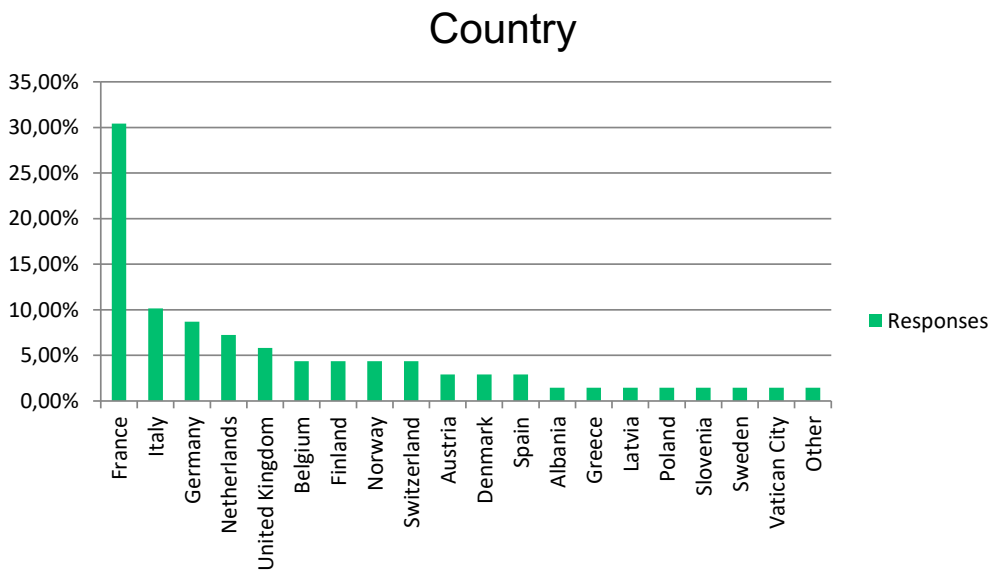


Figure 3: Distribution of survey participants across countries

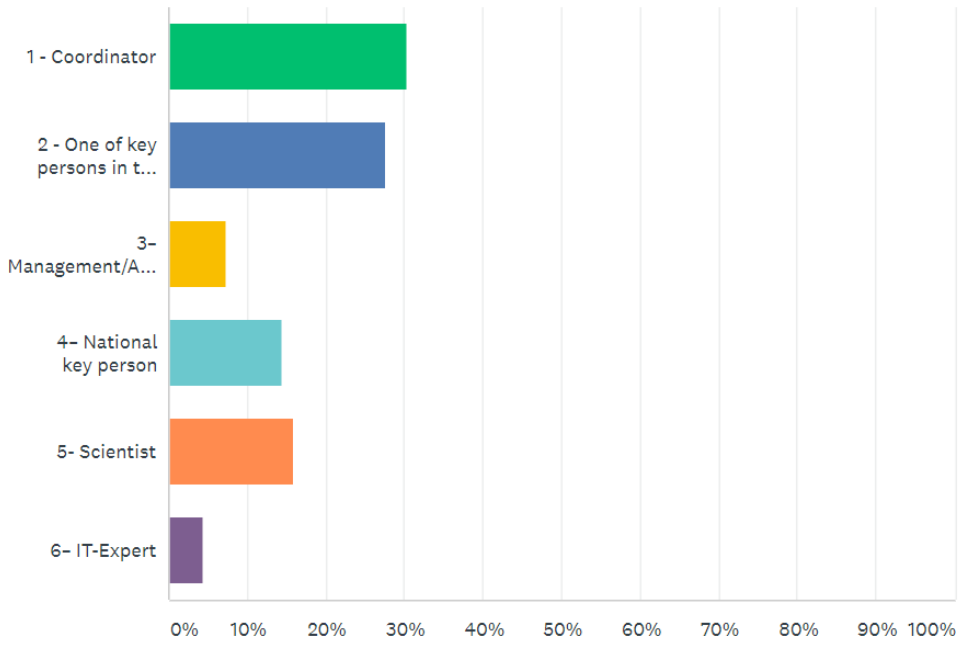


Figure 4: Main role of participants within their RIs (single choice)

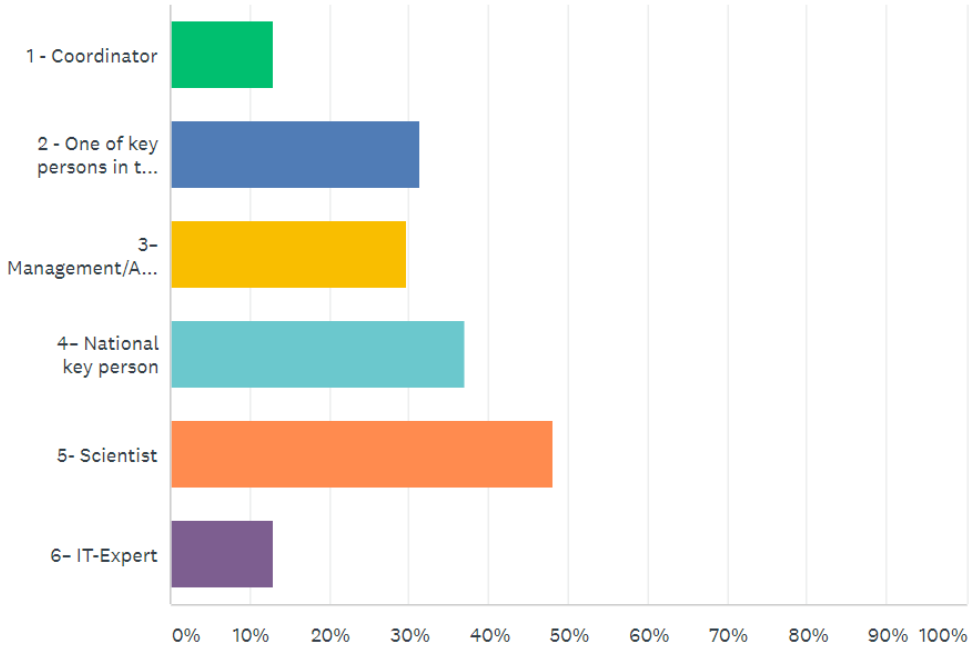


Figure 5: Other roles of participants within their RIs (multiple choice)

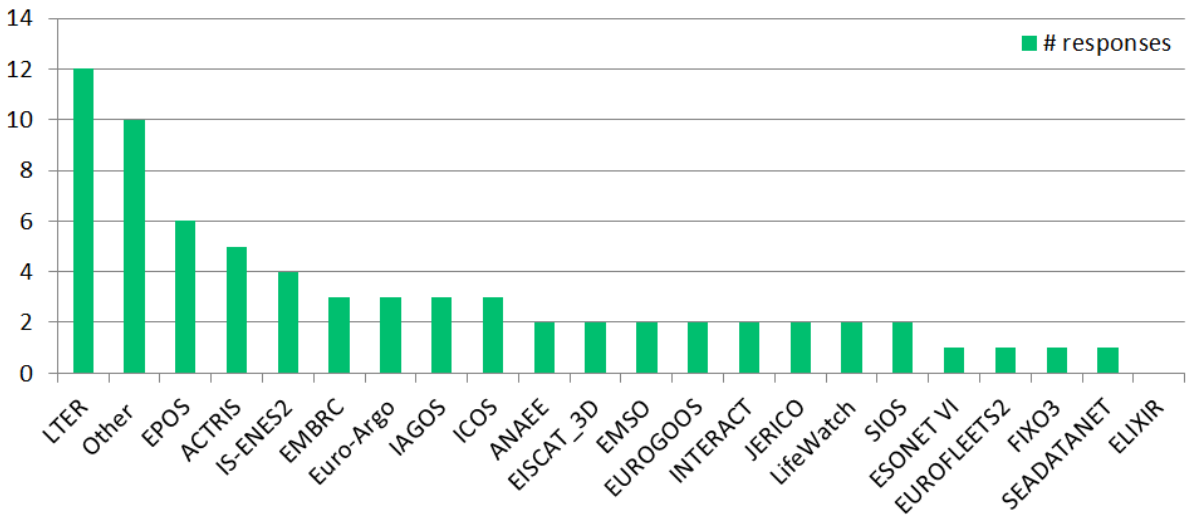


Figure 6: Other roles of participants within their RIs (multiple choice)

3.5.2 Data quality and resulting measures

Not all of the 69 participants provided answers to the highest granularity. 45 persons entered and saved the sections for the granularity 1 (yes/no) and 2 (4 levels). 44 persons entered/saved the section for granularity 3 (expanding on 1-2 GCs of highest relevance for their RIs). Still, not all questions within these sections were completed. The varying primary roles of participants within their RIs substantively contributed to both the probability of quantitatively answering and heterogeneity of information for the same RI.

Given the strategic nature of the exercise, requiring a good overall knowledge of the RI and the semantics of science strategy and science-policy interfaces, the answers of the categories “coordinator” and “one of the key persons in the RI” (see Figure 4) were most complete and consistent. Fortunately we received answers from at least one person per RI belonging to these categories for all RIs but one (ELIXIR). Where not indicated otherwise, our analyses rely on these 40 datasets.

Where more than one dataset per RI was available the arithmetic mean was used: Numbers correspond to mean values of value-transformed classes (“0 - not at all” to 0; “1 – marginally” to 1; “2 – partly” to 3; “3- fully” to 8) and were standardized relative to the individual maximum values of each RI. n corresponds to the total number of surveys for each RI. ACTRIS (n=2), ANAEE (n=2), EISCAT_3D (n=2), EMBRC (n=1), EMSO (n=1), EPOS (n=4), ESONET VI (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), EUROGOOS (n=2), FIXO3 (n=1), IAGOS (n=3), ICOS (n=2), INTERACT (n=2), IS-ENES2 (n=1), JERICO (n=2), LifeWatch (n=2), LTER (n=6), SEADATANET (n=1), SIOS (n=1).

4 Results

4.1 GC Survey results

4.1.1 Overview

Throughout the tables and graphs of this report the following codes and abbreviations are used for the EC and NRC Grand Challenges:

Table 3: Descriptions and abbreviations of the European Grand Challenges (EC1-8) and the US NRC Grand Challenges (NRC1-8). Throughout this report we use light blue to indicate EC Grand Societal Challenges and light red to indicate US National Research Council Grand Challenges.

EC	Abbreviation	Description	NRC	Abbreviation	Description
1	Food agro	Food security agro	1	Biogeochemistry	Biogeochemical Cycles
2	Food non-agro	Food security - non-agro habitats & water	2	Biodiversity	Biological Diversity and Ecosystem Functioning
3	Energy	Energy: New knowledge and technologies	3	Climate	Climate Variability
4	Resilience	Climate: Resource and water efficient and CC resilient economy and society	4	Hydrology	Hydrologic Forecasting
5	Resource management	Climate: Env. protection, sustainable management of natural resources, water, biodiv & ecosystems	5	Diseases	Infectious Disease and the Environment
6	CC adaptation	Climate: Fighting and adapting to CC	6	Resource use	Institutions and Resource Use
7	Observation	Climate: Develop global environm. observation and information systems	7	Land use	Land-Use Dynamics
8	Security	Security: Enhance the resilience of society against natural and man-made disasters	8	Material use	Reinventing the Use of Materials.

The following Table 4 shows a comparative overview for 20 RIs, where contributions to the different ICSU workflow steps were averaged in order to present the focal thematic Grand Challenges at one glance.

Table 4: Standardized mean relevance (%) of the European Grand Challenges (EC1- EC8, blue) and the US NRC Grand Challenges (NRC1-NRC8, red) for different Research Infrastructures (RI) in alphabetical order. Numbers correspond to mean values of value-transformed classes (for details see chapter 3.5). The color coding highlights GCs of highest relevance in dark green. Column headers in bold indicate the five Grand Challenges with mean relevance above 50% across all RIs.

	Food agro	Food non-agro	Energy	Resilience	**Resource-management**	CC Adaptation	**Observation**	Security	**Biogeo-chemistry**	**Biodiversity**	**Climate**	Hydrology	Diseases	Resource use	Land use	Material use	
RI	**EC1**	**EC2**	**EC3**	**EC4**	**EC5**	**EC6**	**EC7**	**EC8**	**NRC1**	**NRC2**	**NRC3**	**NRC4**	**NRC5**	**NRC6**	**NRC7**	**NRC8**	**Mean**
ACTRIS	3	10	23	8	13	15	100	79	3	3	87	23	5	0	5	0	24
ANAEE	94	80	0	30	60	66	6	56	100	90	24	18	0	58	54	0	46
EISCAT 3D	5	10	33	29	5	14	67	0	57	24	57	100	19	14	19	14	29
EMBRC	23	23	10	3	100	63	28	0	100	100	15	0	40	0	0	0	31
EMSO	3	27	0	0	17	13	93	77	50	30	100	0	0	17	0	3	27
EPOS	0	0	1	9	0	4	8	100	0	0	0	0	0	5	0	0	8
ESONET VI	0	16	37	0	100	0	100	68	58	58	16	0	0	0	0	16	29
Euro-Argo	0	18	6	24	65	6	100	0	35	24	94	18	0	0	0	0	24
EUROFLEETS2	29	86	43	0	79	0	100	29	79	79	29	0	0	0	0	0	34
EUROGOOS	16	32	32	21	32	21	100	21	53	26	84	32	3	0	0	0	29
FIXO3	36	84	16	8	56	36	100	84	84	84	84	36	12	36	0	20	49
IAGOS	21	21	9	23	50	59	100	54	30	30	71	30	25	25	25	21	37
ICOS	38	33	25	36	47	87	100	9	76	55	45	16	7	2	13	0	37
INTERACT	0	0	23	0	100	51	56	51	92	92	38	31	0	49	28	3	38
IS-ENES2	19	19	6	19	19	69	6	0	69	19	100	38	6	0	0	0	24
JERICO	17	60	13	86	86	86	100	69	86	86	86	86	63	24	60	0	63
LifeWatch	6	6	0	19	100	26	39	32	0	90	3	0	32	10	6	0	23
LTER	23	54	11	44	100	35	65	39	59	87	70	23	3	14	57	4	43
SEADATANET	9	27	27	0	73	0	100	9	73	73	73	0	0	0	0	0	29
SIOS	80	80	48	30	100	40	40	80	30	100	80	80	30	30	38	10	56
Mean	**21**	**34**	**18**	**19**	**60**	**35**	**70**	**43**	**57**	**57**	**58**	**27**	**12**	**14**	**15**	**5**	**34**

RIs with a broad scope and serving multiple purposes (JERICO, SIOS, ICOS, LTER or FixO3) can be distinguished from specialists like IS-ENES2 (climate modeling), EPOS (security), LifeWatch (biodiversity) or AnaEE (experimentation with focus on food security). High means in the column to the right indicate mainly broad topical RI scopes.

The main messages from this overview are:

- The five focal Grand Challenges of the ENVRIplus RIs (> 50% mean average importance) are
  - EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
  - EC7 Climate: Develop global environm. observation and information systems
  - NRC1 Biogeochemical Cycles
  - NRC2 Biological Diversity and Ecosystem Functioning
  - NRC3 Climate Variability
  -
- Unique and/or complementary niches become visible even at this coarse resolution
-
- Overlaps in scope in combination with considering the RI type (in-situ vs. e-infrastructures) indicate candidates for collaboration and co-location (e.g. same habitat, but different theme)
-
- Half of the GCs reached an average importance of 35% (EC5-8, NRC1-4). This GC selection was used as "priority GCs" in one of the distance matrices (see chapter 4.1.6).

4.1.2 ICSU workflow categories

The RI response to the ICSU Grand Challenges reflecting an overall societal workflow varies strongly across RIs (Figure 7), but shows a clear pattern when considering averages across all ENVRIplus RIs (Figure 8) and – specifically – only the focal Grand Challenges of RIs (Figure 9). This is due to the fact that the RIs contribution to other GCs than "Observing" and "Forecasting" is mainly indirect and/or difficult to quantify, which increased the variability of responses to the survey.

Figure 7: Overview of ENVRIplus RIs average relevance for the ICSU workflow categories Observing, Forecasting, Confining and Responding (columns) within the EC Grand Societal Challenges (rows). Bar charts show the relevance in the granularity level 2 categories "not at all" (green), "marginally" (dark blue), "partly" (yellow) and "fully" (light blue). Percentages on the x-axis indicate the corresponding number-transformations of these categories. The red less-than and greater-than signs and red boxes indicate basic differences in RI responses, which are discussed in the text below.

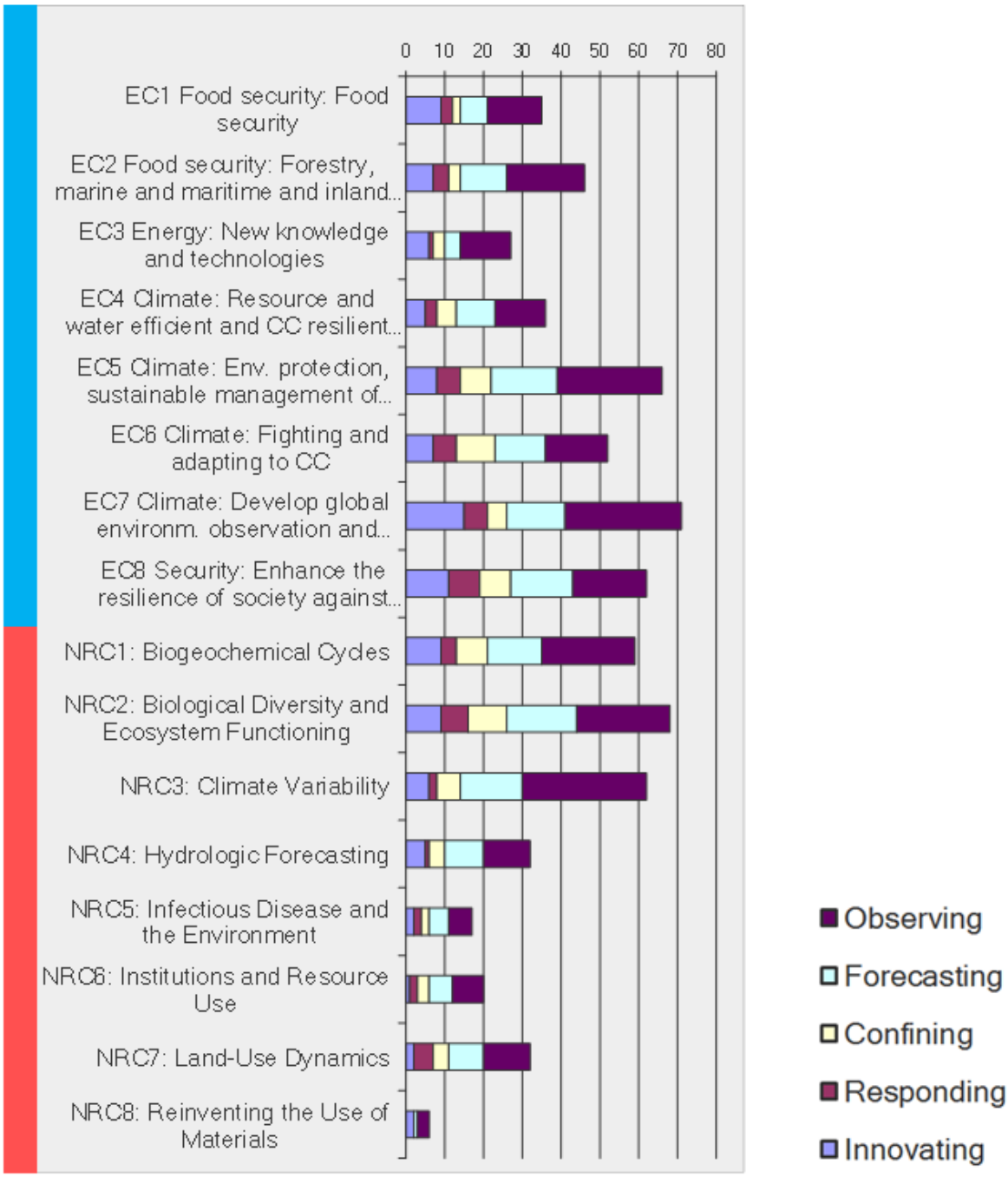


Figure 8: Mean relevance (percent based on number-transformed categories of granularity level 2) of all environmental RIs (across domains) for the ICSU workflow Grand Challenges within all EC Grand Societal Challenges (blue bar to the left) and all NRC Grand Challenges (red bar to the left) in rows.

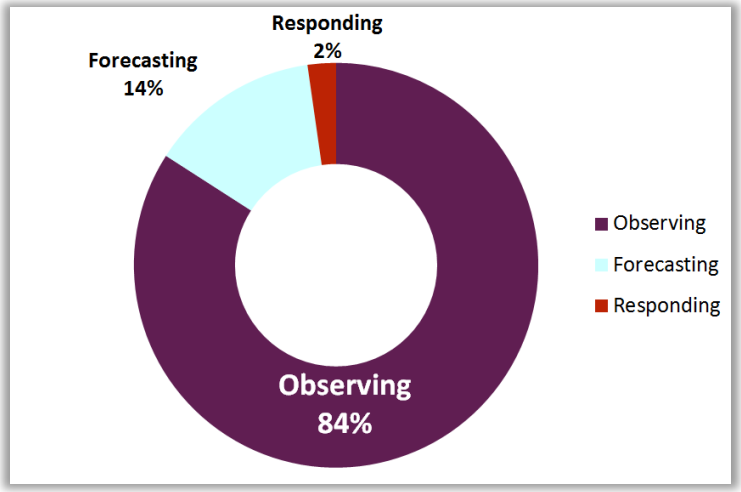


Figure 9: Relevance of RIs concerning the ICSU workflow Grand Challenges with respect to the two Grand Challenges per RI, which were reported as the RIs focal GCs (granularity level 3).

Figure 7 contains bar charts reflecting the ENVRIplus RIs responses to EC Grand Societal Challenges and differentiated for the ICSU workflow categories "Observing", "Forecasting", "Confining" and "Responding". Whereas most EC GSCs are partly to fully addressed through "Observation", only few EC GSCs see RIs contributing to "Confining" activities. Observation – as main service – is followed by "Forecasting" and "Responding". This pattern is most evident for the focal EC GSCs identified in the previous chapter (see Table 4), namely EC5 (Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems) and EC7 (Develop global environm. observation and information systems), where respondents to the survey had by definition less difficulties in quantifying the role of their RIs.

The averages of the number-transformed responses shown in Figure 8 underpin the pattern for both EC GSCs and NRC GCs. As for the EC GSCs, the pattern is most pronounced for the focal NRC GCs: NRC1 (Biogeochemical Cycles), NRC2 (Biological Diversity) and NRC3 (Ecosystem Functioning).

Based on survey responses of highest granularity (level 3), Figure 9 completes the image: When analyzing only the GCs of primary or secondary relevance for RIs, only the ICSU GCs "Observing", "Forecasting and "Responding" occur with 84%, 14% and 2% share, respectively. For more results based on granularity level 3, see chapter 4.1.7.

EPOS can serve to provide a more in-depth look at the ICSU workflow elements by using the example of seismic hazard assessment: In short, and much simplified, seismic hazard assessment provides (probabilistic) estimates of the strength of (earthquake-induced) ground shaking expected to occur in a given region over a defined time-window. This 'high-level data product' is derived from a large set of observational data and their scientific interpretation (incl. earthquake occurrence, geological structure, tectonic setting & geodetic displacement) and provided to society as a set of products covering different aspects of seismic hazard (hazard maps, -curves, -spectra, etc. for different time-windows and scenarios, see e.g. www.efehr.org). These products serve as input to a range of policy development and legislative processes, e.g. the establishment of building codes for earthquake resistant construction both on national and European level (https://eurocodes.jrc.ec.europa.eu/), zoning maps for where to build how strong, specific infrastructure risk assessment (e.g. nuclear power plants, but also deep geothermal power plants or underground CO2 storage facilities). Thus, the observing and forecasting from the scientific community leads to confining and responding by downstream societal actors. These policy-making and legislative processes, and their political discussion, may then (and indeed often do) lead to 'innovation pressure', identifying the need for

better or more data, models or methods to reduce uncertainties and/or increase coverage or detail, feeding back into the observation and forecasting realms and thus closing the circle.

The workflow cycle can also be looked at from a different angle for a much shorter timescale, when one considers the role and impact of RIs in crisis communication and management as in the case of e.g. EPOS. Again this particularly applies to natural hazards (earthquakes, volcanoes, severe weather) where scientific observation and possible forecasting of disastrous events directly feeds into response and mitigation measures, and may lead to societal pressure on the scientists regarding their observation & forecasting results and capabilities. This is investigated and described in detail in ENVRIplus deliverable D12.3 'White Paper on General Guidelines, Recommendations and Best Practices on Communication and Decision Making under Uncertainty for Environmental Hazards and Natural Disasters'.

Summary:

- The ENVRIplus RIs services mainly relate to environmental observation and forecasting
- Contributions to societal response, confining and innovation (consider specific ICSU definition!) are heterogeneous and difficult to quantify, supposedly due to indirect effects.

4.1.3 Comparisons between domains

In the final project phase 26 environmental Research Infrastructures from four domains collaborated in ENVRIplus (Figure 10).

Figure 10: ENVRIplus environmental RIs and their assignment to four environmental domains indicated by RI logos (source: https://www.envriplus.eu/, 2019-05).

In order to analyzed differences in domain specific responses to Grand Challenges, level 2 responses to the GC survey were averaged for EC and NRC Grand Challenges (Figure 11, Figure 12).

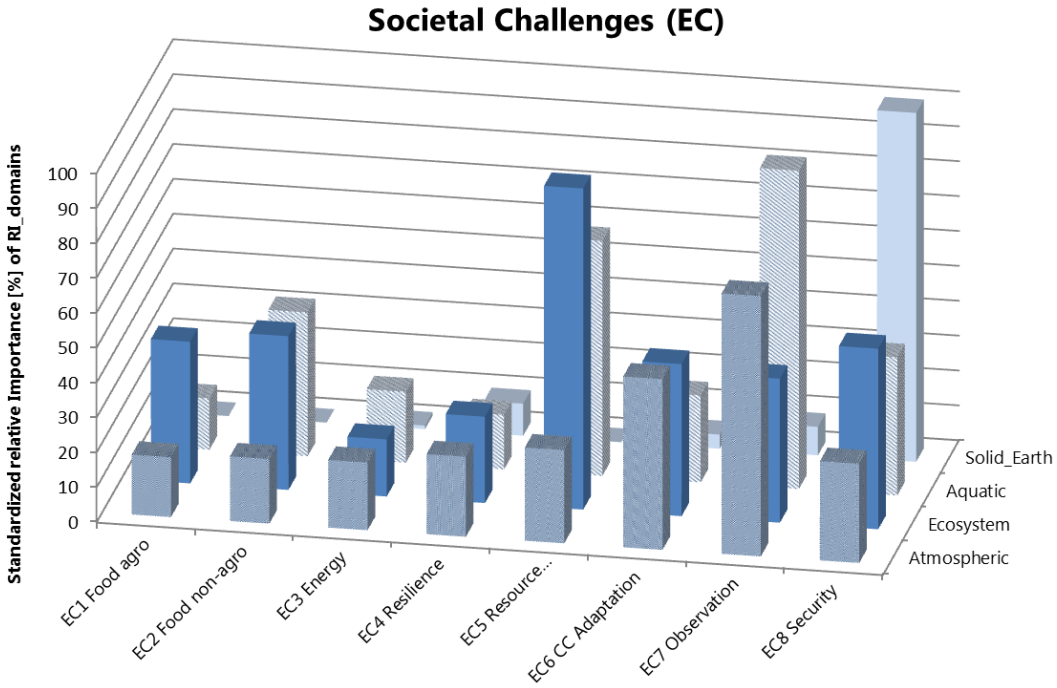


Figure 11: Standardized mean relevance (%) of the European Grand Challenges (EC1- EC8) for different domains of research infrastructures (RI). The aquatic domain (i) comprises the following RIs: JERICO (n=2), FIXO3 (n=1), EMSO (n=1), EUROGOOS (n=2), SEADATANET (n=1), EMBRC (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), ESONET VI (n=1); the atmospheric domain (ii) EISCAT_3D (n=2), ARISE (n=1), IAGOS (n=3), ICOS (n=2), IS-ENES2 (n=1), ACTRIS (n=2); the ecosystem/biosphere domain (iii) ANAEE (n=2), LifeWatch (n=2), LTER (n=6), INTERACT (n=2), SIOS (n=1) and the Solid Earth domain (iv) EPOS (n=4). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

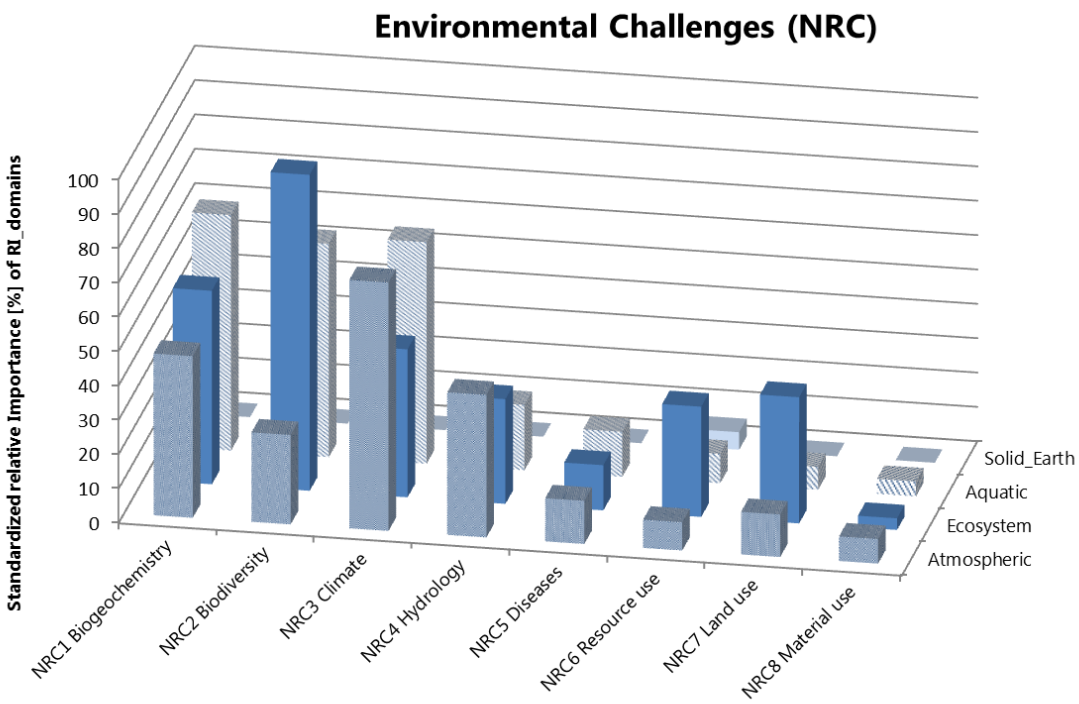


Figure 12: Standardized mean relevance (%) of the US NRC Grand Challenges (NRC1-NRC8) for different domains of research infrastructures (RI). The aquatic domain (i) comprises the following RIs: JERICO (n=2), FIXO3 (n=1), EMSO (n=1), EUROGOOS (n=2), SEADATANET (n=1), EMBRC (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), ESONET VI (n=1); the atmospheric domain (ii) EISCAT_3D (n=2), ARISE (n=1), IAGOS (n=3), ICOS (n=2), IS-ENES2 (n=1), ACTRIS (n=2); the ecosystem/biosphere domain (iii) ANAEE (n=2), LifeWatch (n=2), LTER (n=6), INTERACT (n=2), SIOS (n=1) and the Solid Earth domain (iv) EPOS (n=4). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

The following composed Figures (Figure 13, Figure 14, Figure 15) highlight major domain differences and commonalities.

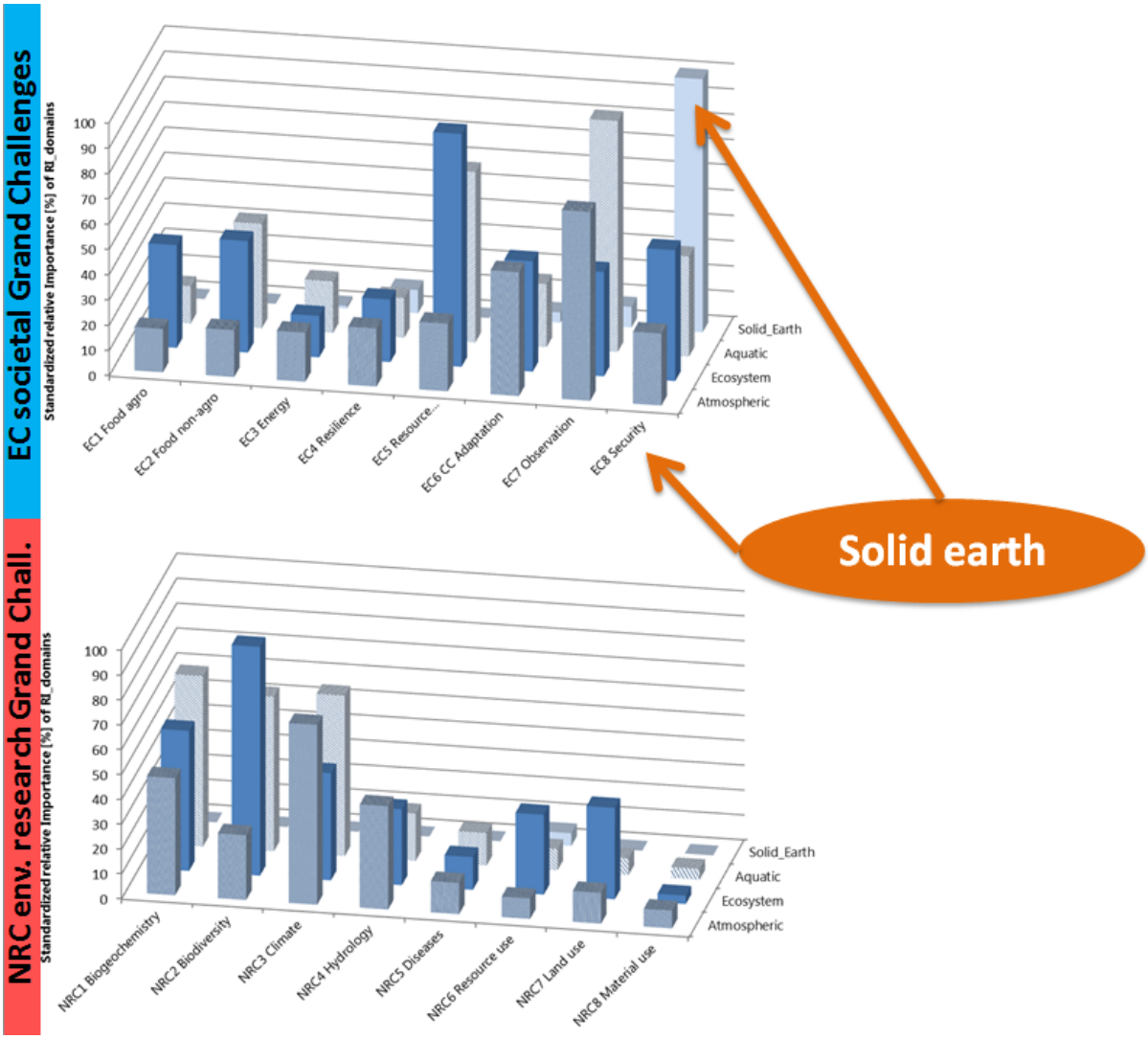


Figure 13: Standardized mean relevance (%) of the EC societal Grand Challenges (upper part) and US NRC Grand Challenges (lower part) for RIs in the four ENVRIplus domains. Arrows highlight the main aspects for the domain "Solid earth" (see following text).

The Solid Earth sciences, in the landscape of European RIs represented by EPOS, clearly occupy a special niche. EPOS has a quite singular connection with EC8 "Security", obviously tied to its impact on the mitigation of geohazards (earthquakes, volcanic eruptions, geological mass movements). The georesources & geo-energies aspect of EPOS and Solid Earth sciences (e.g. www.earthscienceeurope.org (NERC, 2017)) is reflected in attributing minor relevance to specific topics in EC4 (CC resilient societies), EC6 (resource efficiency and raw materials), and NRC6 (institutions and resource use). Whether this outcome arises more from the "modesty" of the EPOS participants to the survey, or rather reflects a topical bias in the Grand Challenges systems cannot be finally decided. Clearly, the role that Solid Earth sciences (can) play e.g. in confining past climatic conditions and developments, was not at the forefront of people's minds when answering the survey (see Chap. 4.1.2). The GC systems descriptions (see Chap. 3) suggest, however, that in particular the geohazards aspect plays a minor role in the presumed challenges for our societies. From a Solid Earth science perspective this might certainly be challenged, given the increased susceptibility of modern societies to large earthquakes or major volcanic eruptions. Nevertheless, even these observations clearly highlight the usefulness of the developed approach for RI characterization in the societal context, as it may lead to critically questioning both the self- as well as the outside-perception of a domain.

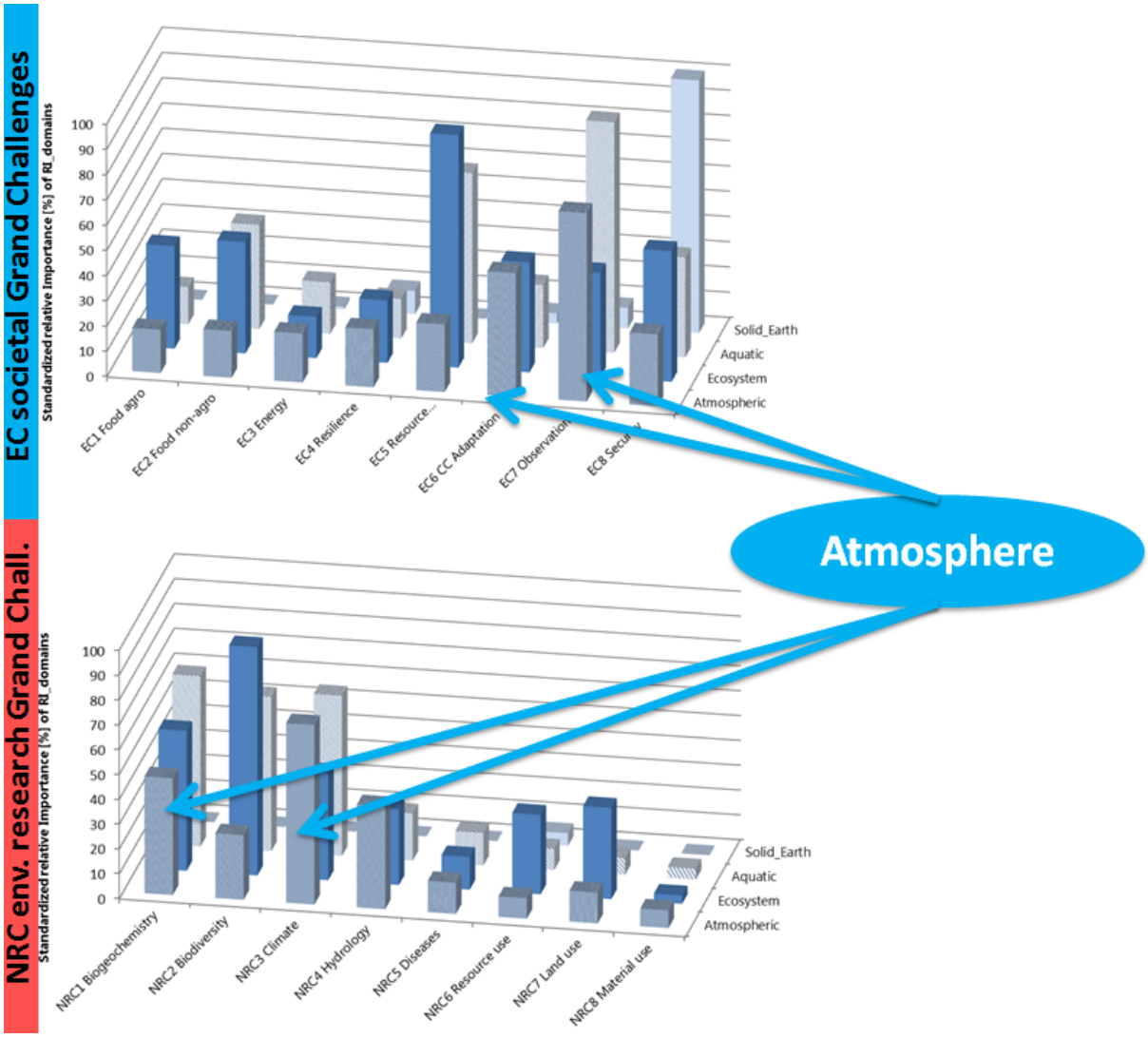


Figure 14: Standardized mean relevance (%) of the EC societal Grand Challenges (upper part) and US NRC Grand Challenges (lower part) for RIs in the four ENVRIplus domains. Arrows highlight the main aspects for the domain "Atmosphere" (see following text).

The responses of atmospheric RIs reflected in Figure 14 correspond strongly with the average ENVRIplus RIs relevance for GCs (see Table 4): Contributions focus on setting up and running environmental observation systems. Observation data serve primarily climate change research and adaptation, followed by biogeochemical cycles and touching upon a wide range of changes related to climate change and altered matter and water fluxes (food security, energy efficiency, resilience and sustainable use of resources).

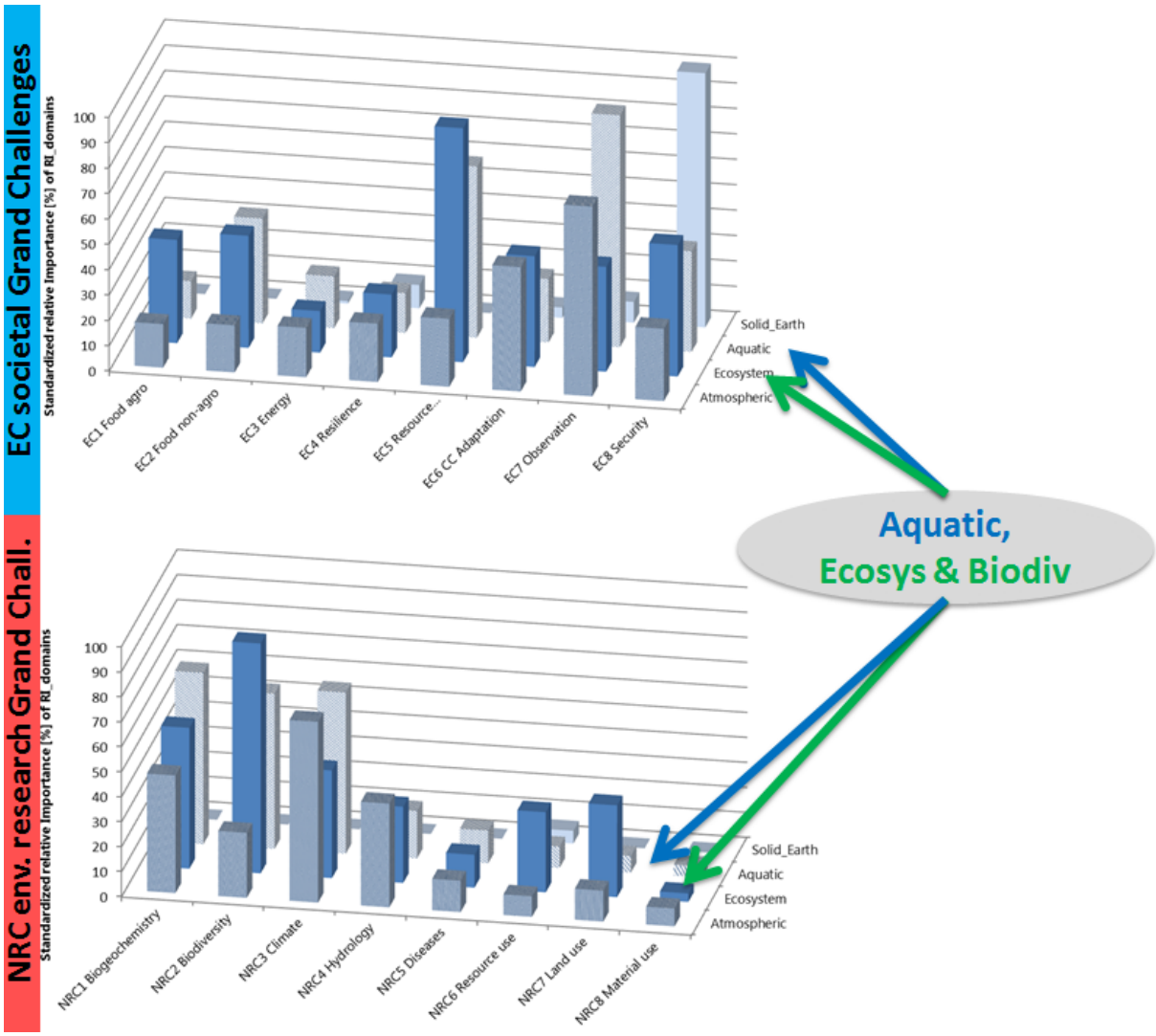


Figure 15: Standardized mean relevance (%) of the EC societal Grand Challenges (upper part) and US NRC Grand Challenges (lower part) for RIs in the four ENVRIplus domains. Arrows highlight the main aspects for the domains "Aquatic/Hydrosphere" and "Ecosystems and Biodiversity" (see following text).

RIs dealing with the hydrosphere, entire ecosystems and biodiversity tend to be challenged by more heterogeneous and complex systems. Consequently, both domains feature a broader range of served GCs with ecosystems/biodiversity reaching the maximum numbers. The sustainable use of resources across scales (EC GCs), and biodiversity and biogeochemistry as main drivers (NRC GCs) clearly constitute the focal GCs of the ecosystems/biodiversity domain, while standardized observation plays an important, but not dominant role. The domain also strongly responds to challenges in the fields of food security, land use and resource use. The marine sub-domain´s role in supporting sustainable fisheries accounts for the strong contribution to GC EC2 ("Food security: non-agro habitats & water").

4.1.4 Exemplary specificities of individual RIs and RI comparisons

This report cannot elaborate on all possible comparisons, but encourages the usage of RI specific information by the individual RIs and groups of RIs. To this end we present example interpretations of the GC survey results for a few selected individual RIs, and also showcase how this categorization can be used for interesting comparisons of different RIs active in the same domain.

4.1.4.1 A cross-domain example: ICOS- ACTRIS-eLTER

While ICOS focusses greenhouse gases in a multi-domain approach and featuring an ecosystem component, the comprehensive, ACTRIS represents a comprehensive set atmospheric observations covering also short-lived compounds. eLTER features a "whole system approach", where variables characterizing the lower atmosphere are indispensable for judging the overall functioning of indicator ecosystems across European gradients. By definition, eLTER focus lies on supporting nature based solutions with biodiversity playing an important role. All three are in-situ RIs, but vary in the role of standard observations and design scale. With respect to the Grand Challenges response profile, this study could provide an easily comprehensible graphical representation of differences and commonalities (Figure 16).

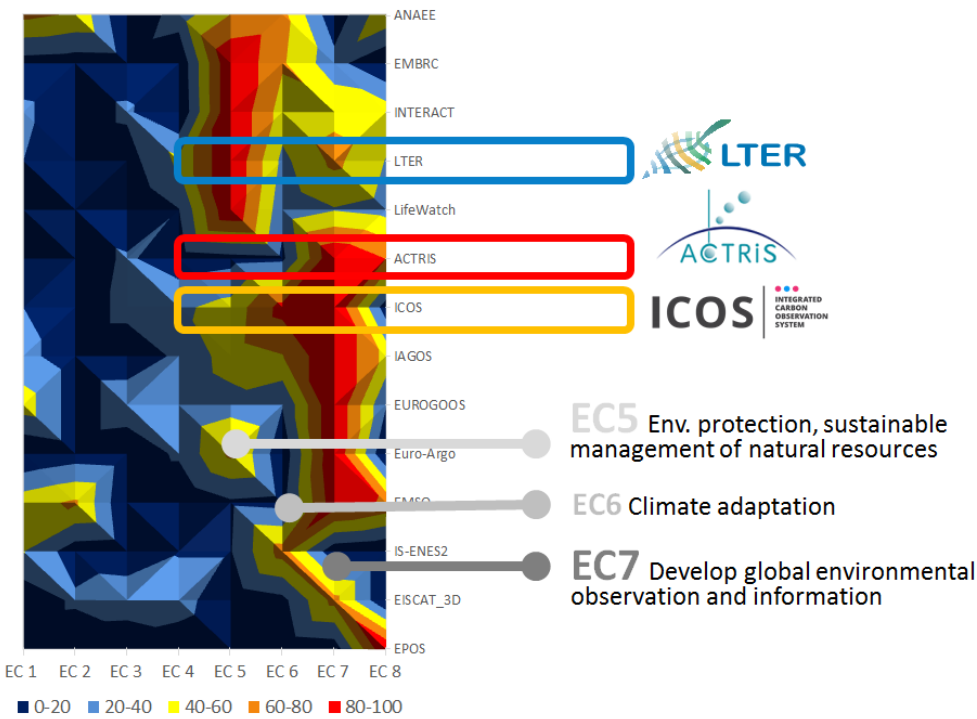


Figure 16: Heat map based on relative GC relevance in %, reflecting the profile of RIs (y-axis) with respect to the EC societal Grand Challenges (x-axis) of highest relevance for European environmental RIs. The focus of most RIs clearly lies in EC 5 Climate (Environmental protection, sustainable management of natural resources, water, biodiversity & ecosystems) or EC 7 Climate (Develop global environmental observation and information systems) or a combination of both.

Figure 16 underpins the emphasis on EC 5 Climate (Environmental protection, sustainable management of natural resources, water, biodiversity & ecosystems) and EC 7 Climate (Develop global environmental observation and information systems) or a combination of both. As for ACTRIS, the most comprehensive atmospheric observation programme causes a sole peak in the graph, distinguishing it from ICOS and eLTER. ICOS thematic focus on CC and CC adaption and ecosystem component results in a wider peak across EC7, EC6 and (less pronounced) EC5. In line

with the scope described above, eLTER features a pronounced “sustainability peak” in EC5 and a lower peak in “standard observations” (EC7), which play mainly a supporting role in the RI.

For details of the respective GC response profiles see Figure 17 and Figure 18.

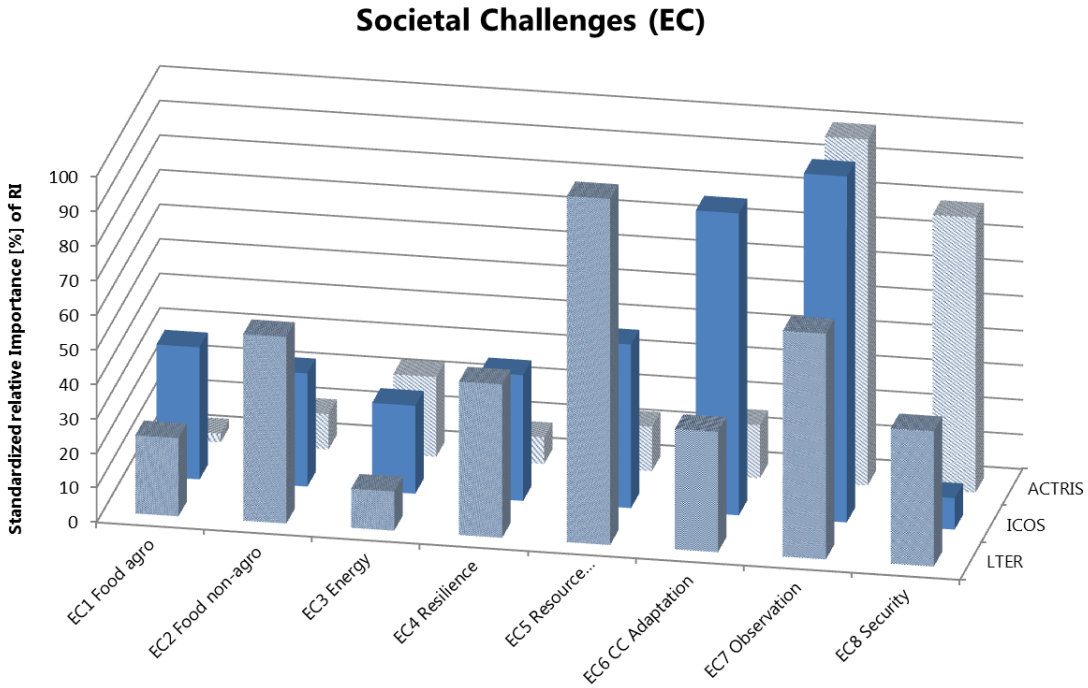


Figure 17: Standardized mean relevance (%) of the European Grand Challenges (EC1- EC8) for different research infrastructures ACTRIS (n=2), ICOS (n=2) and LTER (n=6). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

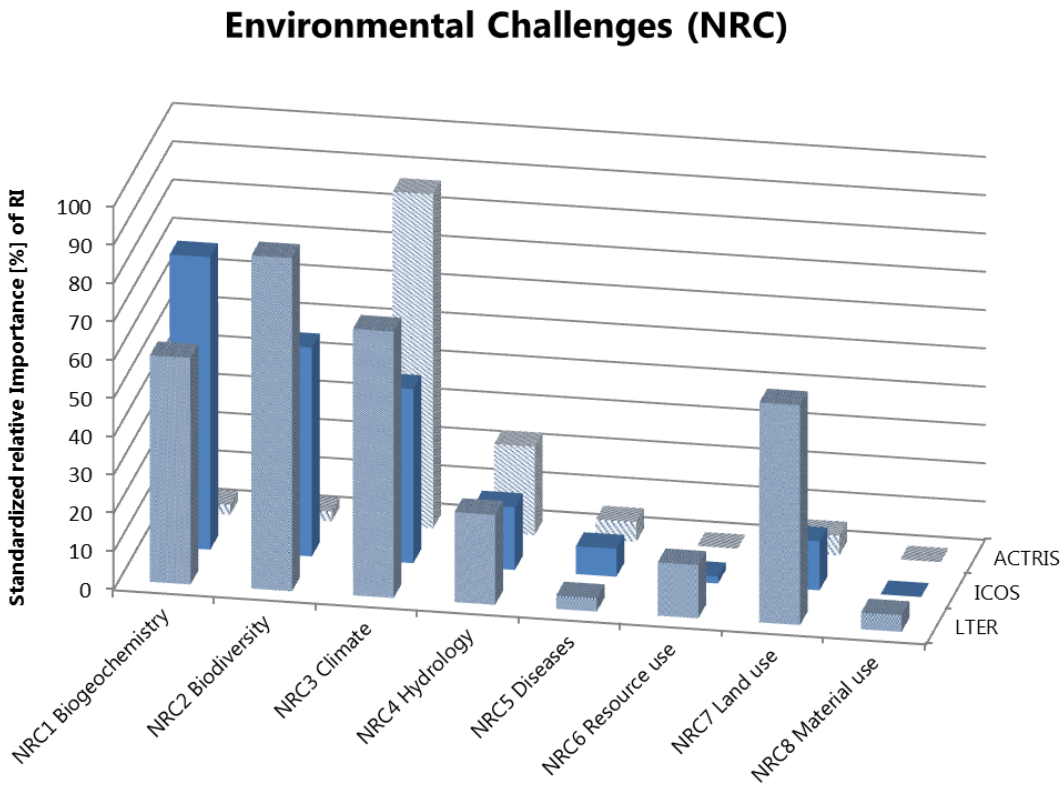


Figure 18: Standardized mean relevance (%) of the US NRC Grand Challenges (NRC1-NRC8) for different research infrastructures ACTRIS (n=2), ICOS (n=2) and LTER (n=6). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

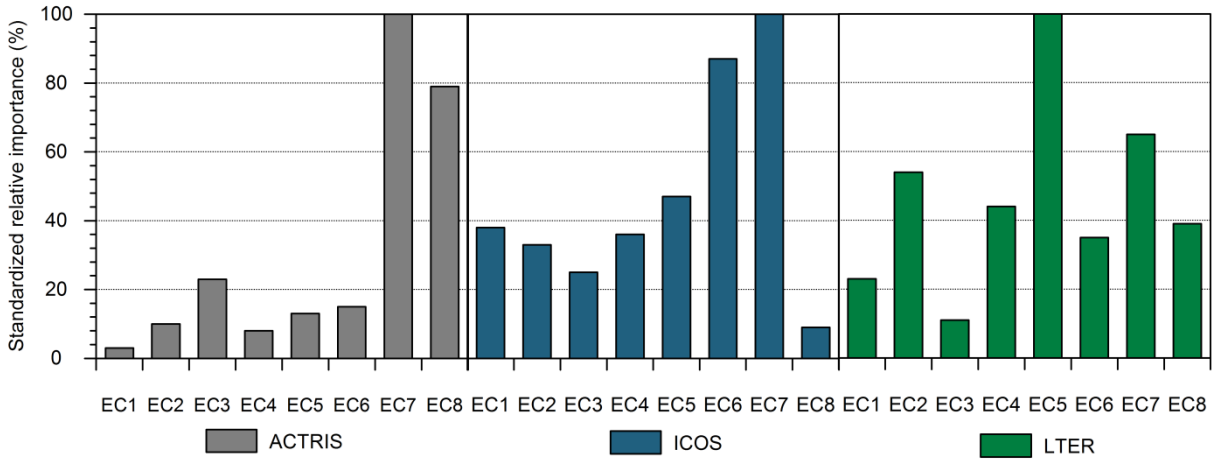


Figure 19: EC Grand Challenges (EC1-EC8) standardized mean relevance (%) for the research infrastructures ACTRIS (n=2), ICOS (n=2) and LTER (n=6). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

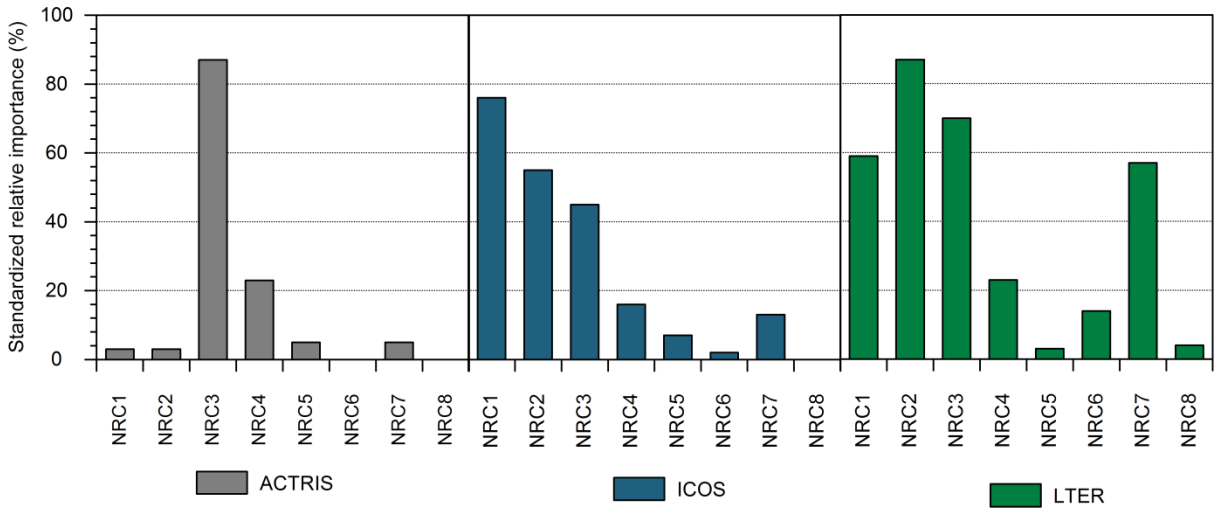


Figure 20: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for the research infrastructures ACTRIS (n=2), ICOS (n=2) and LTER (n=6). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

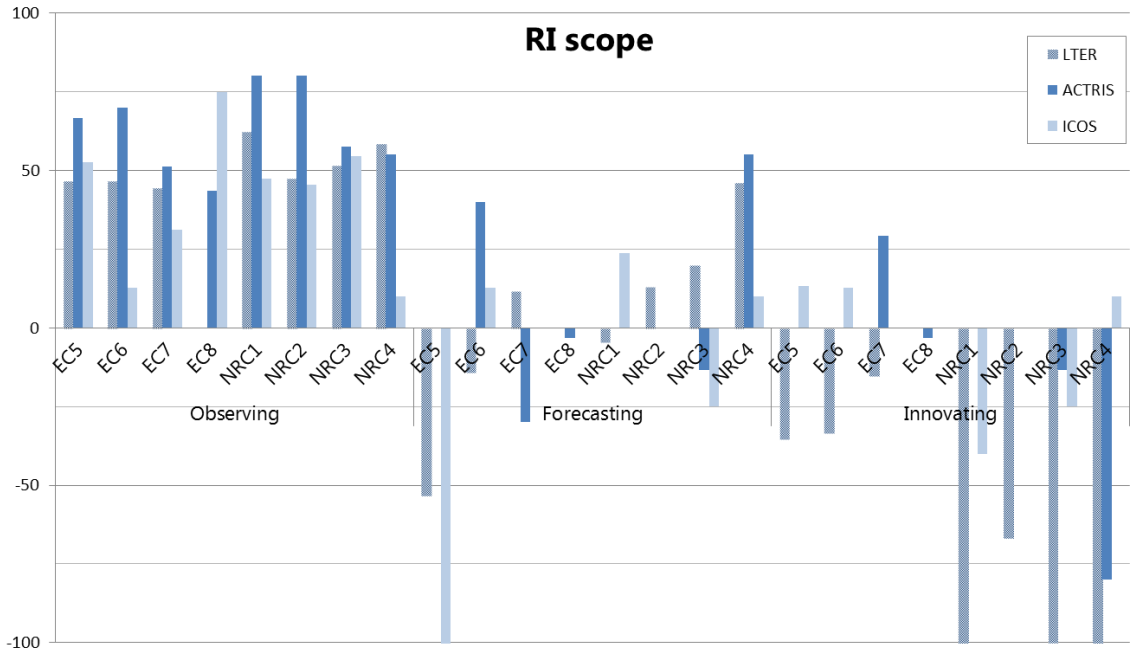


Figure 21: Relevance of the four priority European Grand Challenges (EC5- EC8) and US NRC Grand Challenges (NRC1-NRC4) in the RIs LTER, ACTRIS and ICOS in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100.

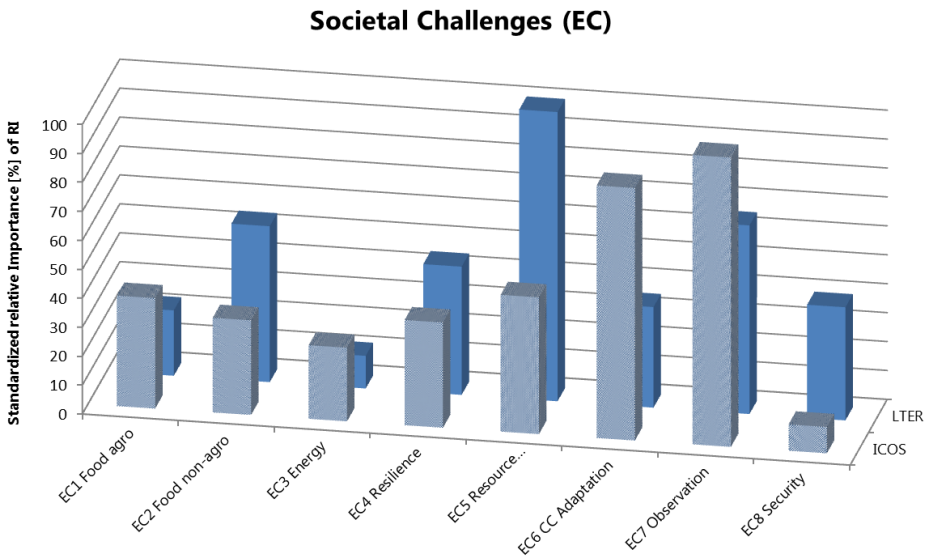


Figure 22: EC Grand Challenges (EC1- EC8) standardized mean relevance (%) for LTER (n=6) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

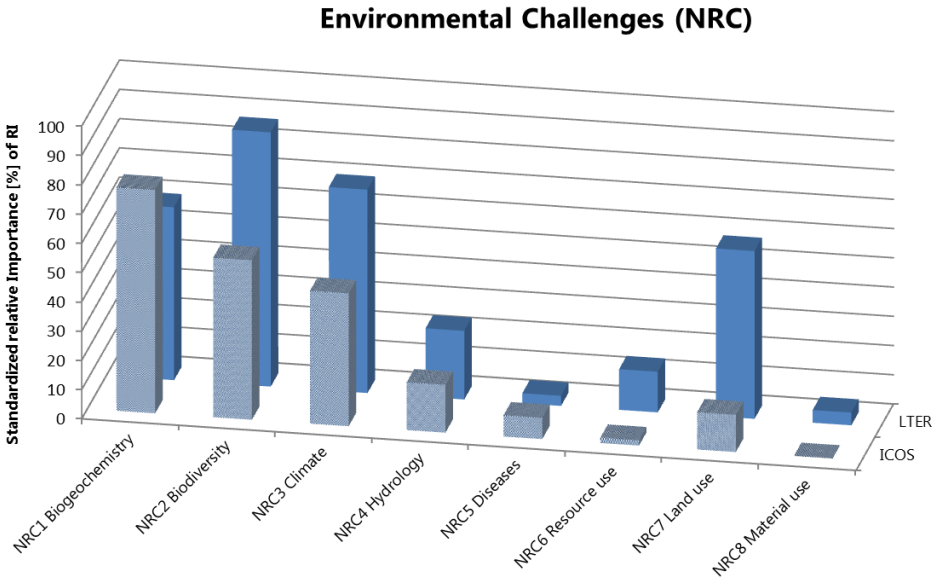


Figure 23: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for LTER (n=6) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

4.1.5 Domain-wise analysis of the results

In the next step, the data were analysed within the four domains of the environmental field. As a technical simplification, bi- or multi-domain RIs were put into one category, particularly ICOS and into atmosphere, SIOS into ecosystem and EMSO into hydrosphere.

4.1.5.1 Ecosystem & BioDiv RIs: In-situ observation, experimentation and e-infrastructures

The first example highlights the **difference between two kinds of in-situ RIs (INTERACT, SIOS) and an e-infrastructure (LifeWatch)**. To this end, Figure 24 shows a comparison between their individual relevance for the main EC and NRC Grand Challenges, and the average of all RIs response to ICSU workflow part (observing-forecasting-innovating). The outcome gives an impression, which RIs do over- or under proportionally contribute to the workflow parts, - and for which GCs. INTERACT provides quite generic infrastructure enabling access into a harsh environment, while SIOS serves the entire chain from access to observation and scientific analyses. This leads to the positive values for both in observing, but the higher relevance of SIOS for forecasting and innovation, where INTERACT shows largely negative values. The role of LifeWatch in supporting data access and analytical workflows in biodiversity research leads to top values in the “forecasting” (central part) with EC5 (sustainable resources) and NRC2/3 (biodiversity under climate change) as focal GCs.

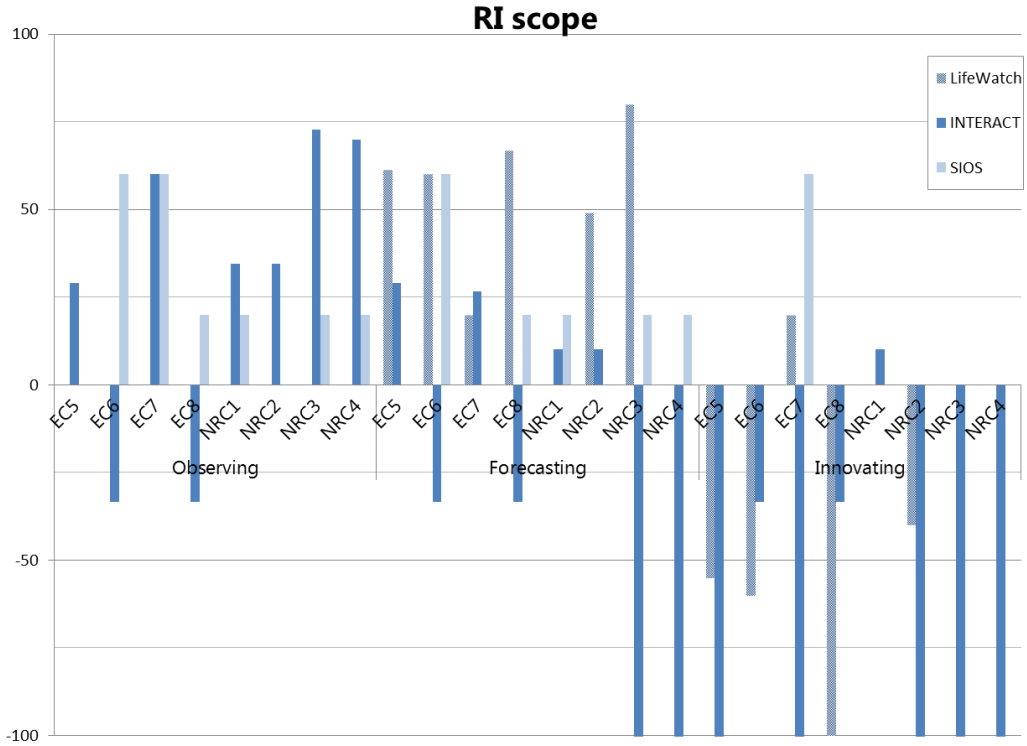


Figure 24: Relevance of the four priority European Grand Challenges (EC5- EC8) and US NRC Grand Challenges (NRC1-NRC4) in the RIs LifeWatch, INTERACT and SIOS in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100

Another interesting comparison reveals **differences between observation and experimentation** as represented by eLTER and AnaEE. Figure 25 and Figure 26 show the raw data on their responses to EC and NRC GCs. In line with AnaEE´s approach of experimental treatments mainly targeted at contributions to food security of terrestrial production systems under climate change, it reaches top values in EC1, EC2, EC6 and NRC1, whereas eLTER scores high in EC5, EC7 and NRC7. Still, given the different and complementary nature one might have expected more pronounced differences.

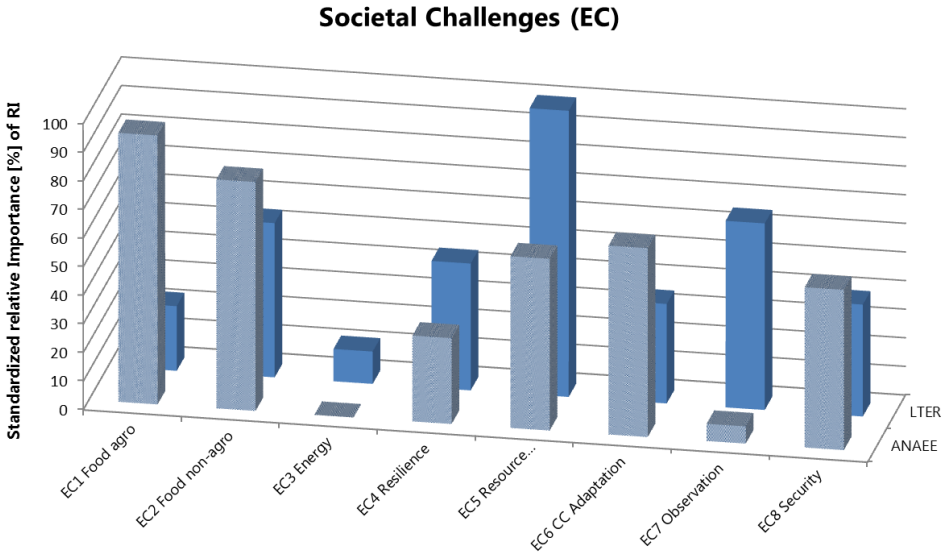


Figure 25: EC Grand Challenges (EC1- EC8) standardized mean relevance (%) for different research infrastructures LTER (n=6) and ANAEE (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

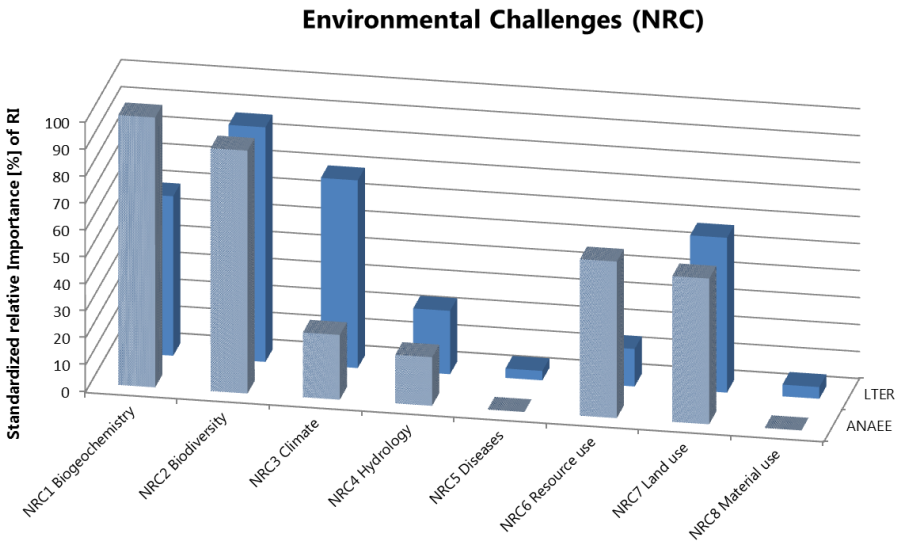


Figure 26: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for different research infrastructures LTER (n=6) and ANAEE (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

However, calculating the same delta matrix as for SIOS, LifeWatch and INTERACT before, the peculiarities become evident at one glance (

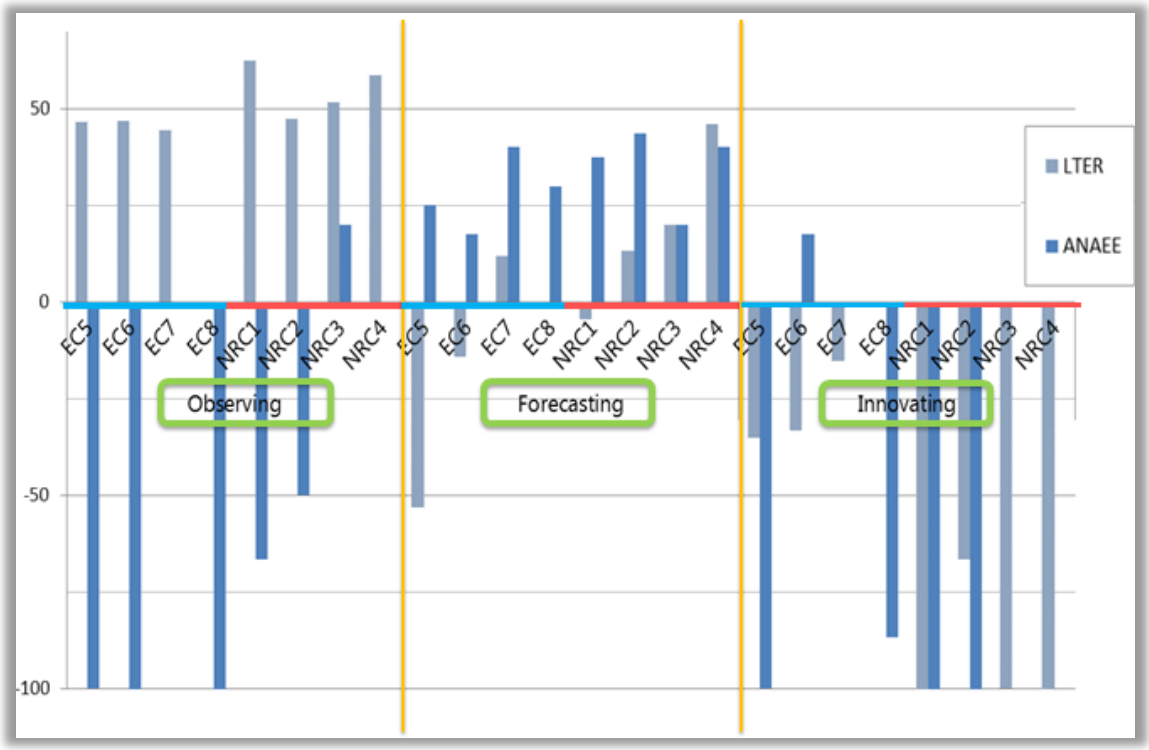


Figure 27):

- While eLTER over proportionally scores in “observing”, AnaEE´s role in providing experimental results on simulations of possible future environmental conditions is clearly reflected by strong contributions to “forecasting”
- Both are research infrastructures, handing over their results into other societal innovation processes (low values for direct “innovation”) in the overall societal collaboration (see also Figure 49).

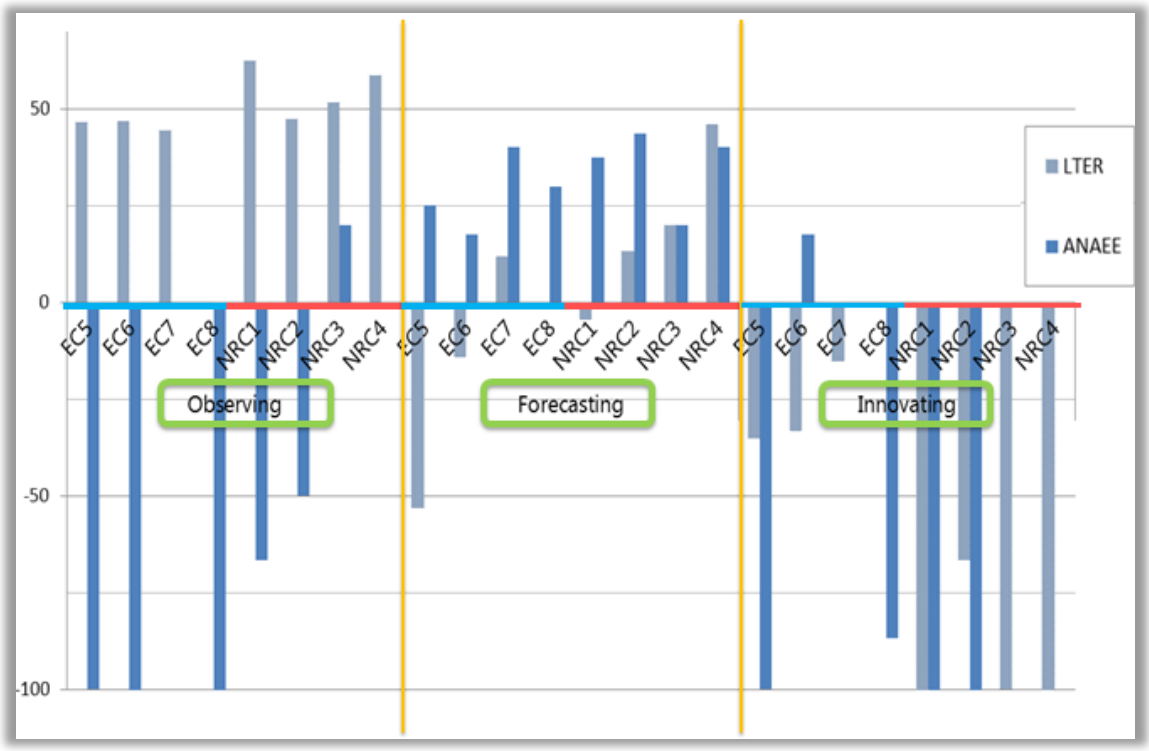


Figure 27: Relevance of the four priority European Grand Challenges (EC5- EC8, indicated by light blue lines on the x-axis) and US NRC Grand Challenges (NRC1-NRC4, indicated by light red lines on the x-axis)) in the RIs LTER and ANAEE in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating; green boxes) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100

For further comparisons between RIs of the ecosystems and biodiversity domain in ENVRIplus see Figure 28 and Figure 29.

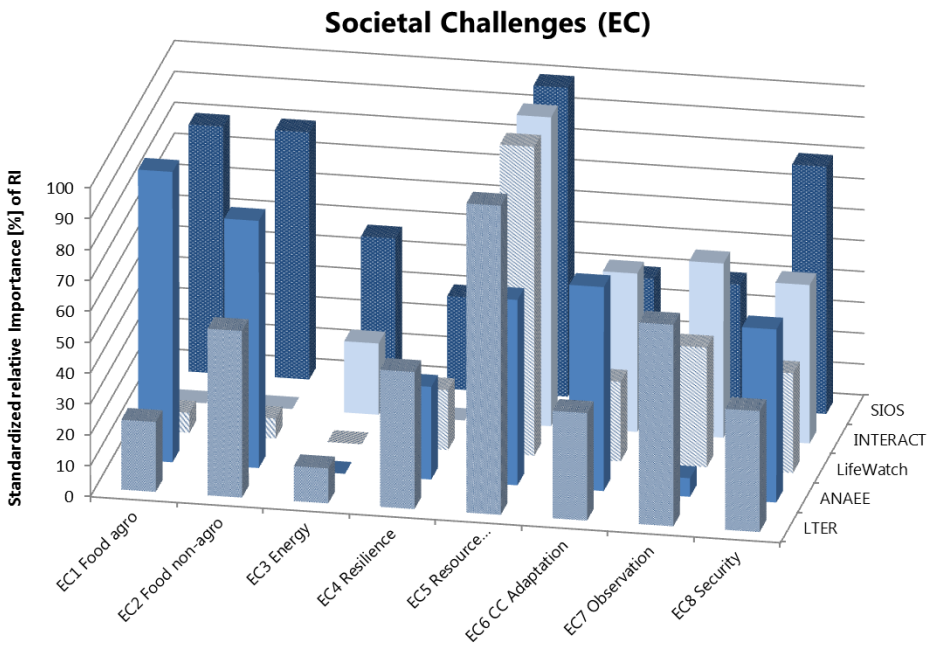


Figure 28: Standardized mean relevance (%) of the European Grand Challenges (EC1- EC8) for ecosystem and biodiversity domain RIs. Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

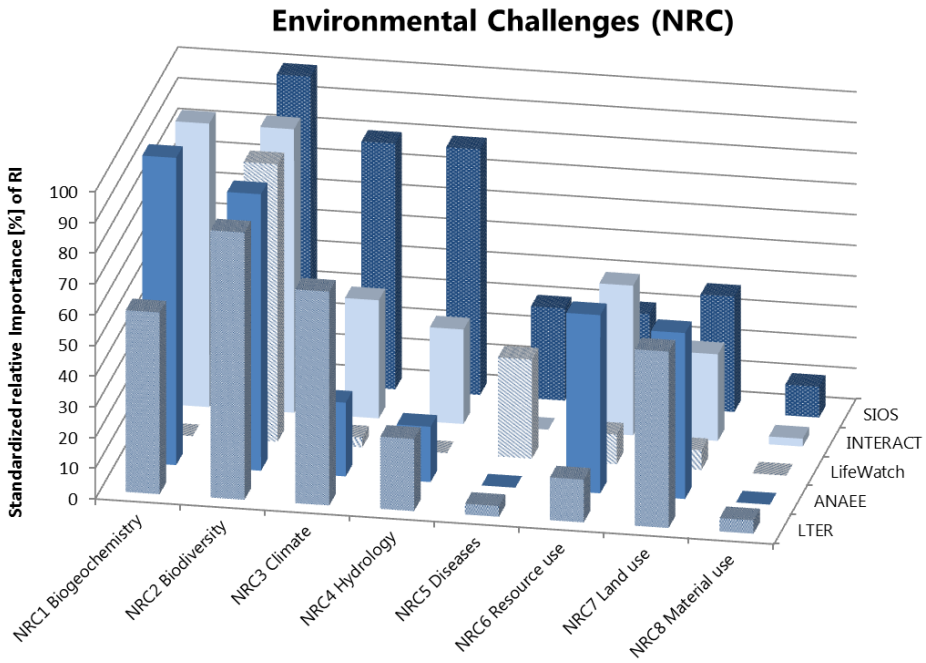


Figure 29: Standardized mean relevance (%) of the US NRC Grand Challenges (NRC1-NRC8) for ecosystem and biodiversity domain RIs.. Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

4.1.5.2 EPOS (solid earth)

With respect to EPOS (see also chapter 4.1.3 & 4.1.7, and Figure 13) the European Plate Observing System www.epos-eu.org, which is the only environmental RI in the solid Earth domain (but covers solid Earth sciences quite comprehensively), it was rapidly obvious that the participating national & academic research infrastructures (also encompassing observational "data gathering" infrastructures with limited or no research component like seismic or geodetic networks) clearly focus their operational and research activities on observing and forecasting (utilizing the observed data). Resulting knowledge (i.e. the scientific interpretation of the observations) is then provided to other stakeholders in society as input to inform policy- and decision-making. The role of the RIs and their individual scientists then changes from the "active agent" that directly drives and conducts the research to an "expert advisor" that supports the responsible entities in their decision making and policy formulating activities.

4.1.5.3 Atmospheric domain RIs

The atmosphere in the larger sense comprises ten RIs that are described in detail in Deliverable 17.6 (Franz et al. 2019). Since they are differing in their maturity, sustainability and methods ranging from long-term atmospheric observation platforms and one network of experimental platforms to model development and numerical experiments and since the not all have been represented in ENVRIplus, this analysis of the atmospheric RIs focuses on ICOS, IAGOS and ACTRIS, which have clearly distinguishable target activities on in situ ground-based observations of long-lived GHGs (ICOS), Aerosols, Clouds and short-lived gases (ACTRIS) and plane-based atmosphere profile observations of both (IAGOS). All three RIs see themselves mostly related to EC7 (all 100%). However, ICOS is thereafter more focusing on EC6 and EC5, while ACTRIS relates itself much more to EC 8 with IAGOS always being in between.

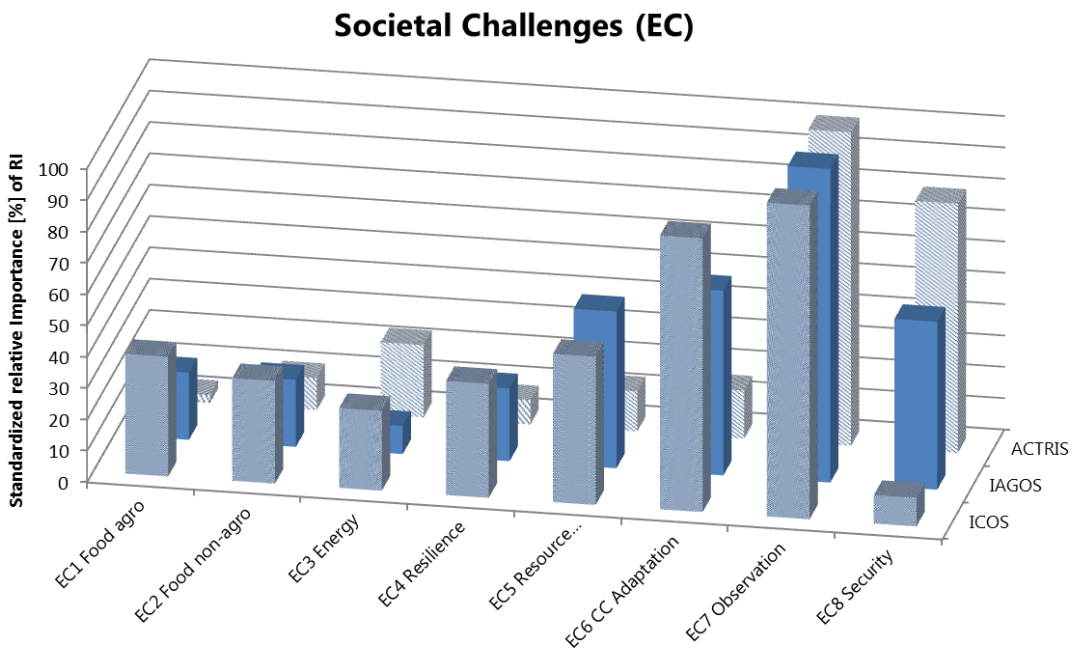


Figure 30: EC Grand Challenges (EC1-EC8) standardized mean relevance (%) for different research infrastructures ACTRIS (n=2), IAGOS (n=3) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

In the NRC system, ICOS has put itself more into understanding of the biogeochemical cycles driving GHG fluxes than into developing the ability to predict climatic variations as IAGOS and ACTRIS did increasingly. This difference may be rooted in the multi-domain character of ICOS.

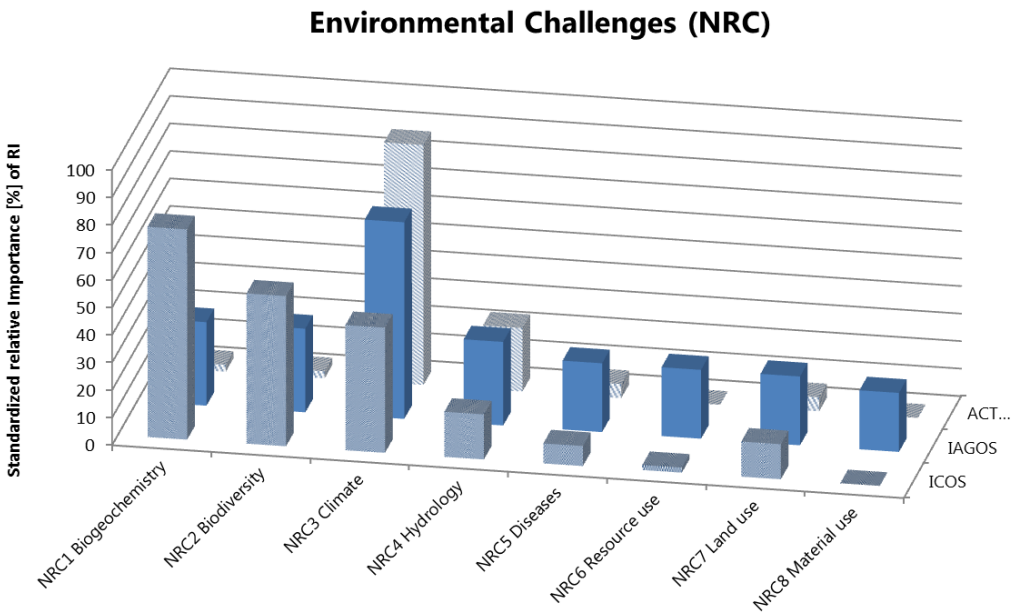


Figure 31: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for different research infrastructures ACTRIS (n=2), IAGOS (n=3) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

The more specialist niche of ACTRIS with a more narrow ('specialist') focus on two Grand challenges can also be seen in the following graph where ICOS and IAGOS show a broader ('generalist') relationship to the GCs.

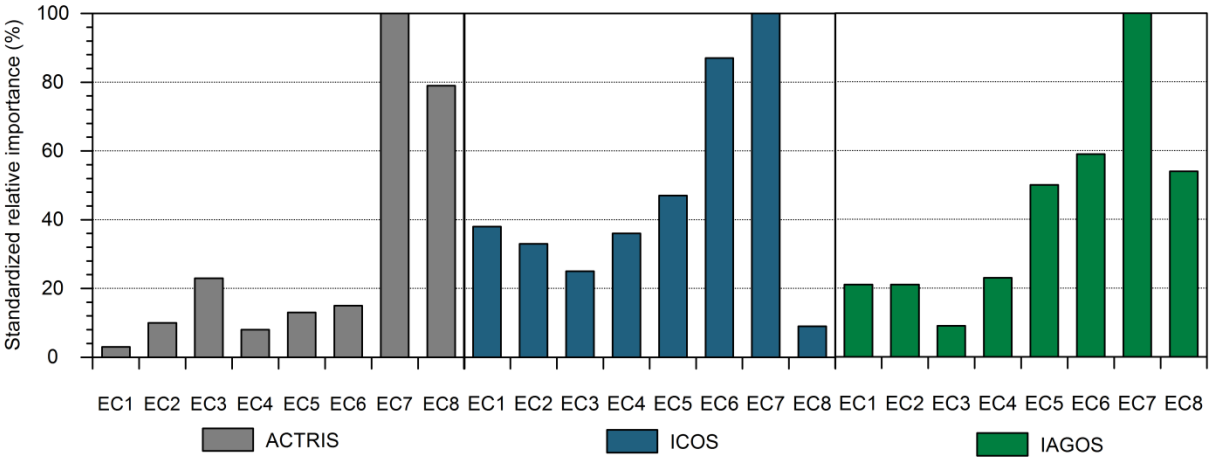


Figure 32: EC Grand Challenges (EC1-EC8) standardized mean relevance (%) for the research infrastructures ACTRIS (n=2), IAGOS (n=3) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

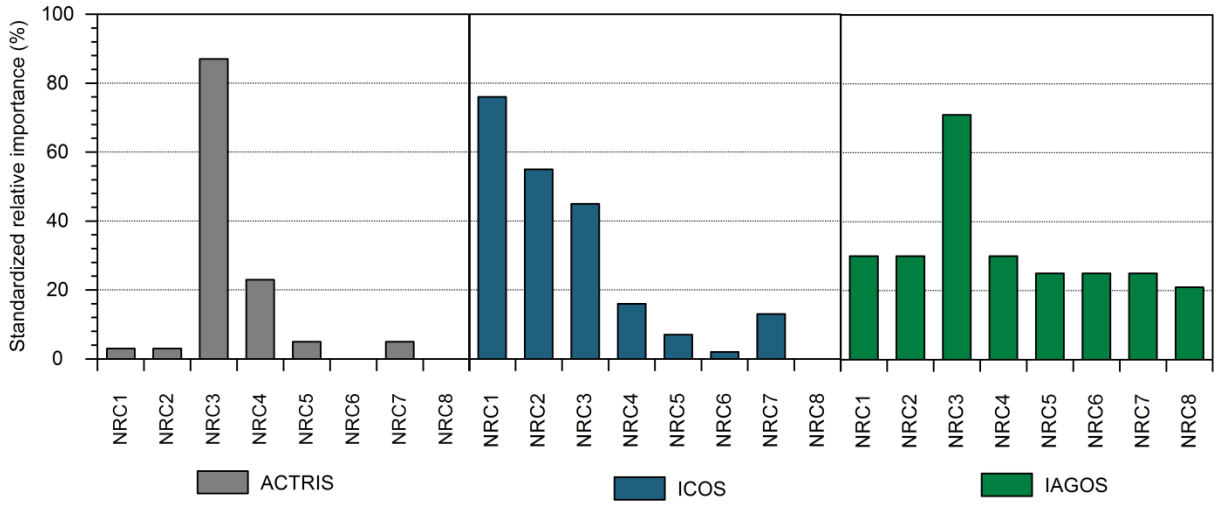


Figure 33: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for the research infrastructures ACTRIS (n=2), IAGOS (n=3) and ICOS (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

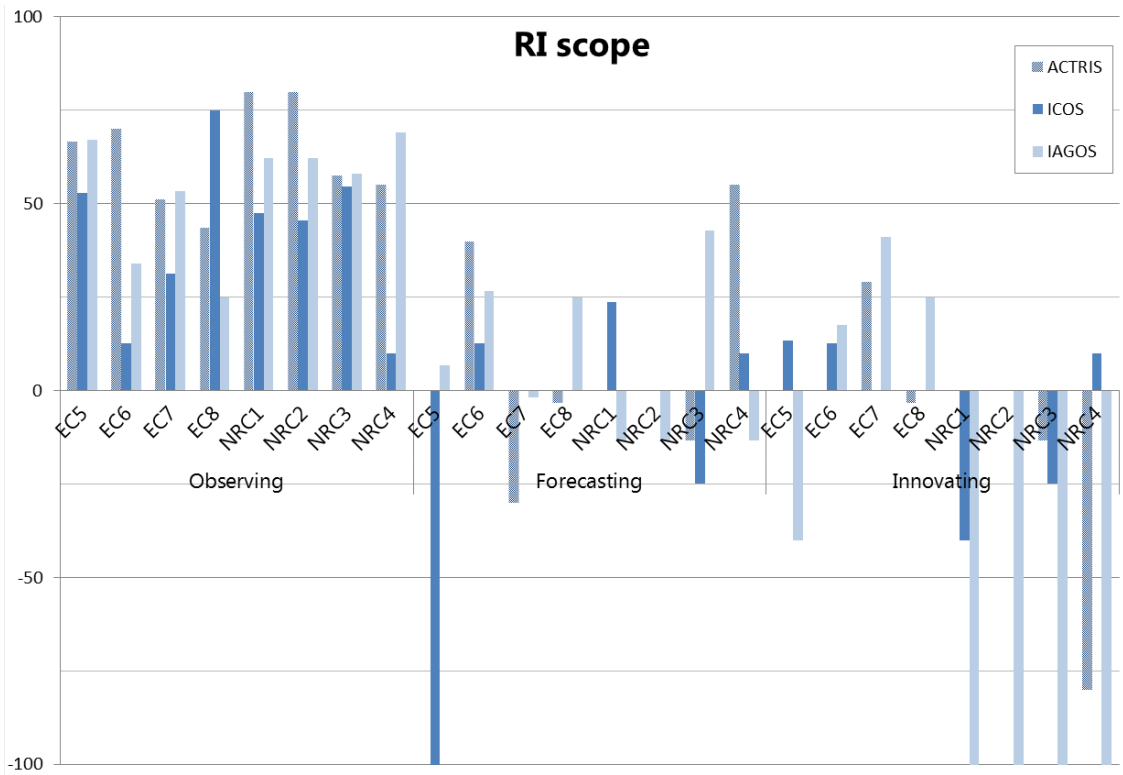


Figure 34: Relevance of the four priority European Grand Challenges (EC5- EC8) and US NRC Grand Challenges (NRC1-NRC4) in the RIs ACTRIS, ICOS and IAGOS in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100

4.1.5.4 Hydrosphere RIs

The hydrosphere landscape is complex and contains in the larger sense fourteen RIs that are described in detail in Deliverable 17.6 (Franz et al. 2019). Since they are differing in their maturity, sustainability and methods. In this study, only nine were considered to avoid double counting (ICOS, Lifewatch, eLTER) and because of the fact that DANUBIUS RI and Aquacosm were connected to ENVRIplus too late to participate in the survey.

Most of the RIs have highest relation to EC7 with highly varying secondary variables. Patterns are difficult to see which may be the result of different scopes of the RIs ranging from observational to data and even coordination infrastructures. The picture in the NRC system is similar.

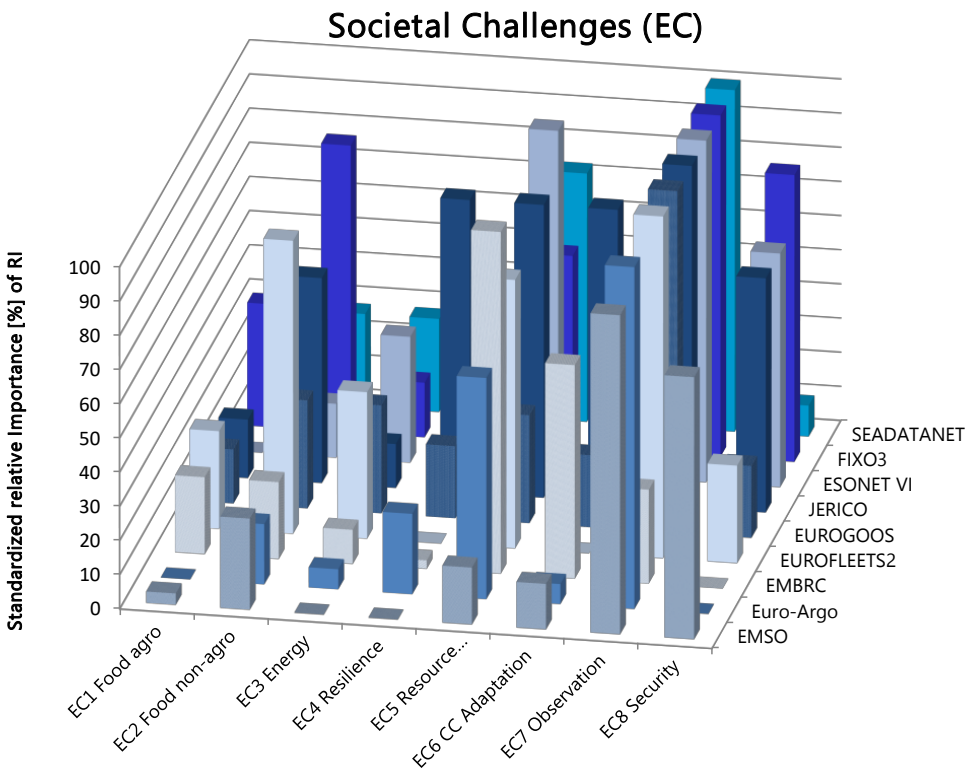


Figure 35: EC Grand Challenges (EC1-EC8) standardized mean relevance (%) for different hydrosphere research infrastructures EMSO (n=1), Euro-Argo (n=2), EMBRC (n=1), EUROFLEETS2 (n=1), EUROGOOS (n=2) and JERICO (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

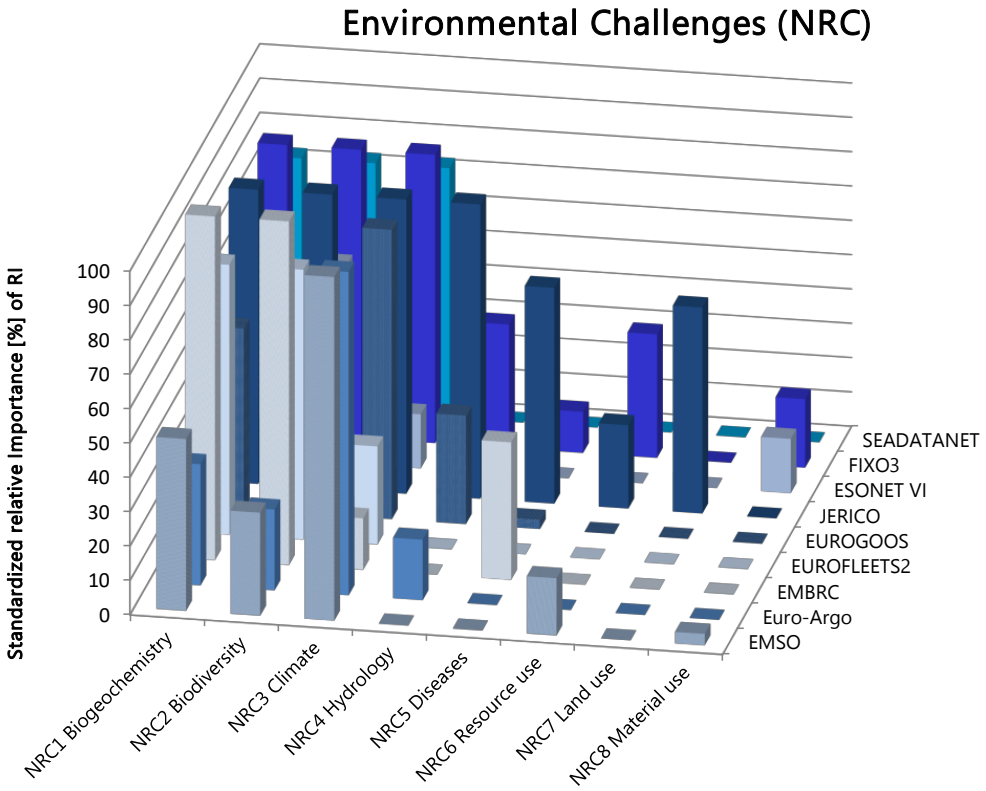


Figure 36: US NRC Grand Challenges (NRC1-NRC8) standardized mean relevance (%) for different hydrosphere research infrastructures EMSO (n=1), Euro-Argo (n=2), EMBRC (n=1), EUROFLEETS2 (n=1), EUROGOOS (n=2) and JERICO (n=2). Numbers correspond to mean values of value-transformed classes (0 - not at all to 0, 1 – marginally to 1, 2 – partly to 3, 3- fully to 8) and were standardized relative to the individual maximum values of each RI.

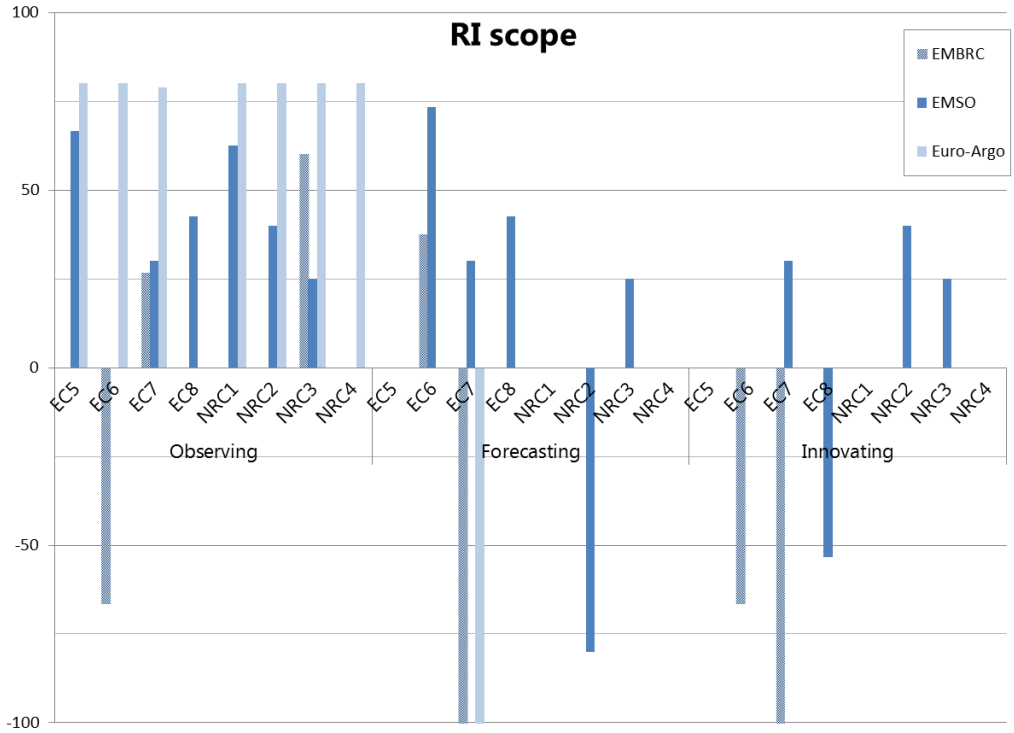


Figure 37: Relevance of the four priority European Grand Challenges (EC5- EC8) and US NRC Grand Challenges (NRC1-NRC4) in the RIs EMBRC, EMSO and Euro-Argo in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100

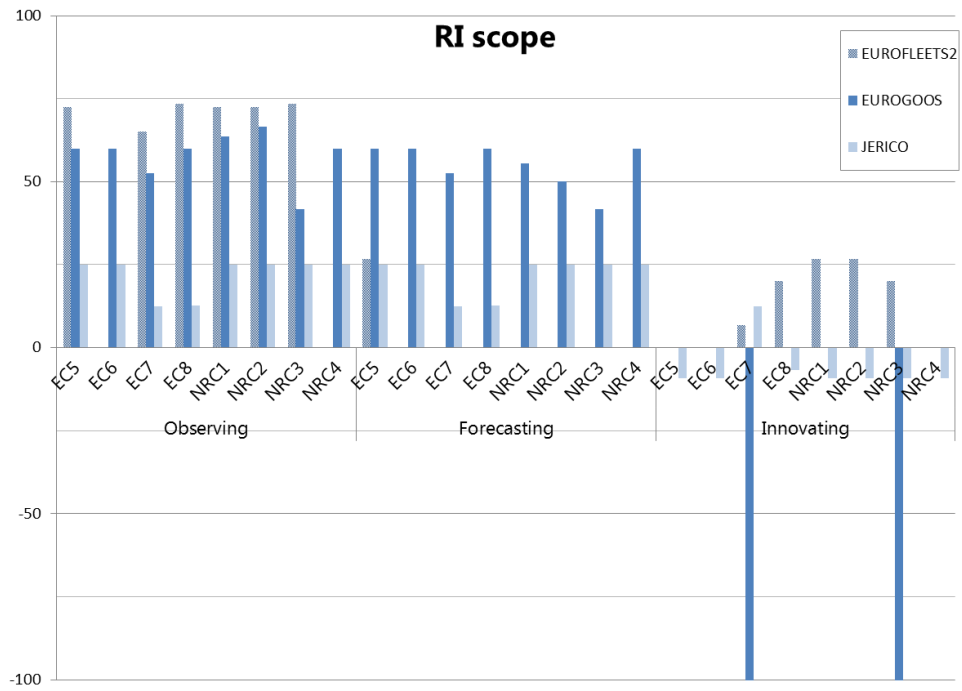


Figure 38: Relevance of the four priority European Grand Challenges (EC5- EC8) and US NRC Grand Challenges (NRC1-NRC4) in the RIs EUROFLEETS2, EUROGOOS and JERICO in relation to the mean relevance of the priority Grand challenges in the ICSU workflow (observing, forecasting and innovating) across all RIs. Numbers correspond to deviations in % of respective value-transformed classes. Value = 0 indicates, that the RI relevance for a given thematic GC (EC GCs, NRC GCs) is identical with the average contribution to the ICSU workflow part across all RIs. Values > 0 indicate, that a given RI´s activities over proportionally contribute to a given ICSU workflow part. Values below -100 were set to -100

4.1.6 Searching for RI similarities and clusters in response to GCs

In search of similarities amongst RIs in their response to GCs two methods were applied, namely distance matrices and cluster analyses:

- For the distance matrices we used all EC Grand Challenges (EC1- EC8) and all US NRC Grand Challenges (NRC1-NRC8) in Figure 39, only EC GCs (Figure 40), only NRC GCs (Figure 41), and the main EC and NRC GCs as identified in chapter 4.1.1 (Figure 42).
- As for the hierarchical cluster analysis (Figure 43), the use of k-means of the standardized mean relevance (%) of all EC and NRC GCs and choice of five clusters gave the most meaningful results.

Apparent special roles, niches and outliers:

- The special aspects and rather singular role of EPOS in this GC framework, as already noted in chapter 4.1.3 and 4.1.5.2 are again clearly visible in these distance matrices, in particular when considering only the priority EC and NRC challenges together (Fig. 44). That the EC and NRC challenge systems emphasize different aspects of societal relevance (EC more on the societal / political side, NRC more focusing on research & development) is to some extent reflected in the EC (Figure 40) and NRC (Figure 41) distance matrices: in the societal / political aspects of the EC GCs, EPOS finds itself somewhat closer to ACTRIS and EMSO only, whereas in the research aspects of the NRC GCs, EPOS seems to have at least some commonalities with a few more of the observation-focused RIs (see also Figure 43).
- JERICO: throughout distance matrices a special role, which is underpinned by the cluster only containing JERICO in the cluster analysis: our impression was, that JERICO respondents ranked JERICO contributions to GCs unusually high, both in terms of the level of relevance and the number of addressed GCs
- AnaEE and SIOS appear as different in distance matrices AND represent the extremes of a separate cluster in the cluster analysis (s. below). Possible reasons are in both cases unique RI characteristics: AnaEE does actually not belong to the environmental domain of ESFRI, but to the health and food domain. It deals with experimental treatments mainly targeted at contributions to food security of terrestrial production systems and not environmental observation *sensu-stricto*. SIOS firstly concentrates on the arctic environment and secondly represents the smallest spatial scale and coverage of all ENVRIplus RIs, namely the island of Svalbard.

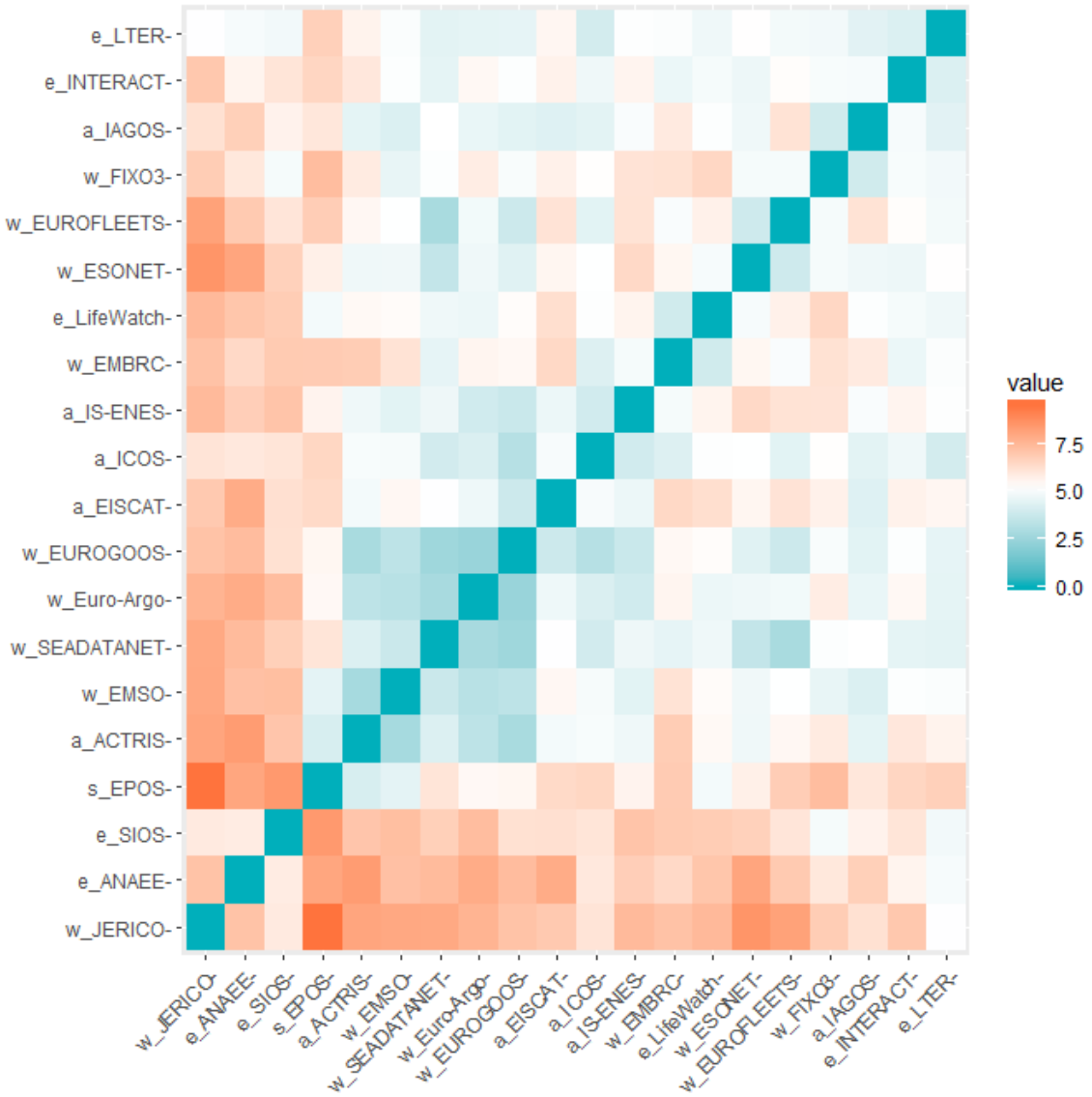


Figure 39: Distance matrix visualizing the standardized mean relevance (%) of the EC Grand Challenges (EC1- EC8) and the US NRC Grand Challenges (NRC1-NRC8) for different research infrastructures (RI): ACTRIS (n=2), ANAEE (n=2), EISCAT_3D (n=2), EMBRC (n=1), EMSO (n=1), EPOS (n=4), ESONET VI (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), EUROGOOS (n=2), FIXO3 (n=1), IAGOS (n=3), ICOS (n=2), INTERACT (n=2), IS-ENES2 (n=1), JERICO (n=2), LifeWatch (n=2), LTER (n=6), SEADATANET (n=1), SIOS (n=1). Distance matrix was computed by the Euclidean distance using the R package 'factoextra' version 1.0.5.

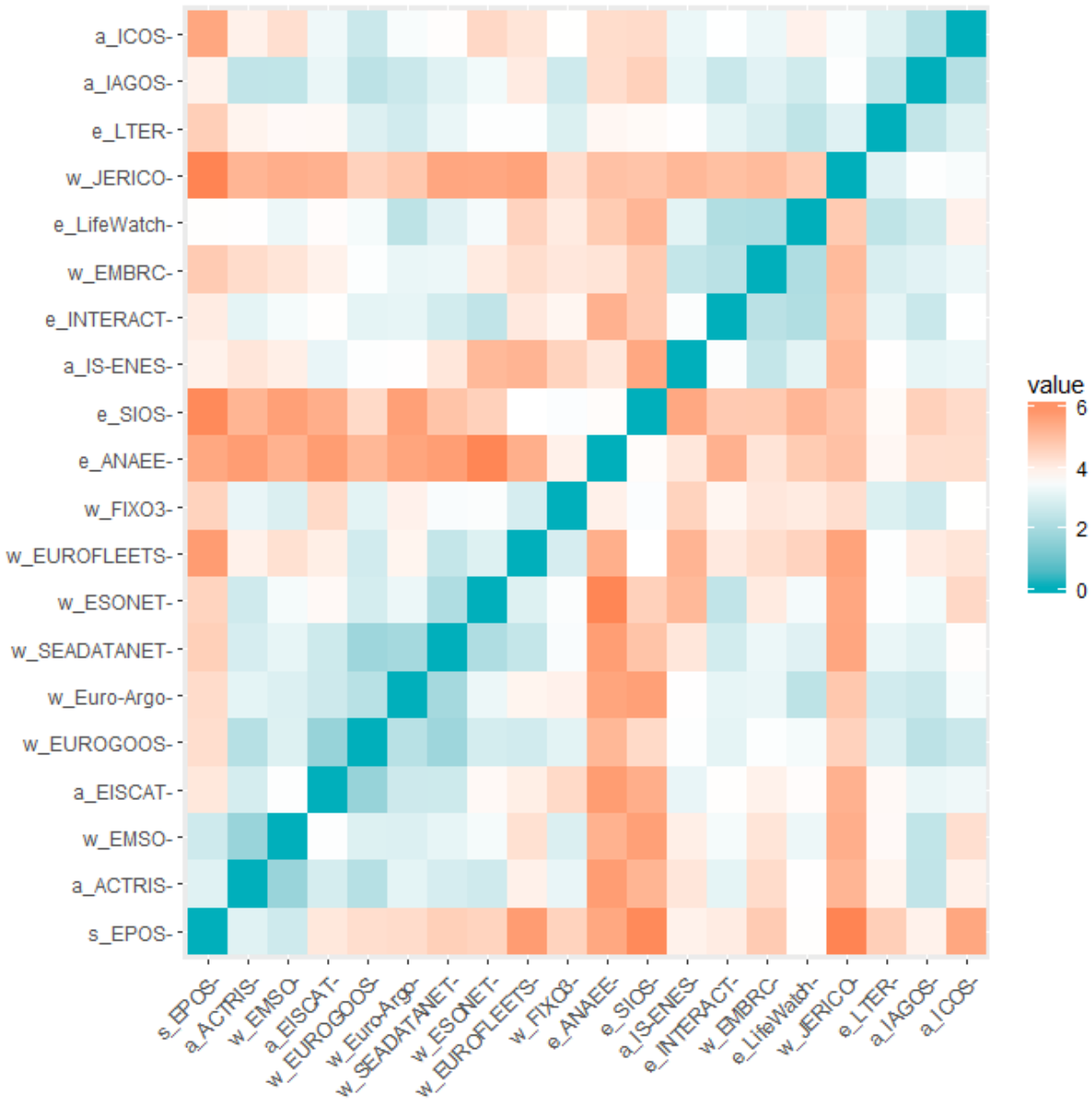


Figure 40: Distance matrix visualizing the standardized mean relevance (%) of only the EC Challenges (EC1- EC8) for different research infrastructures (RI): ACTRIS (n=2), ANAEE (n=2), EISCAT_3D (n=2), EMBRC (n=1), EMSO (n=1), EPOS (n=4), ESONET VI (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), EUROGOOS (n=2), FIXO3 (n=1), IAGOS (n=3), ICOS (n=2), INTERACT (n=2), IS-ENES2 (n=1), JERICO (n=2), LifeWatch (n=2), LTER (n=6), SEADATANET (n=1), SIOS (n=1). Distance matrix was computed by the Euclidean distance using the R package 'factoextra' version 1.0.5.

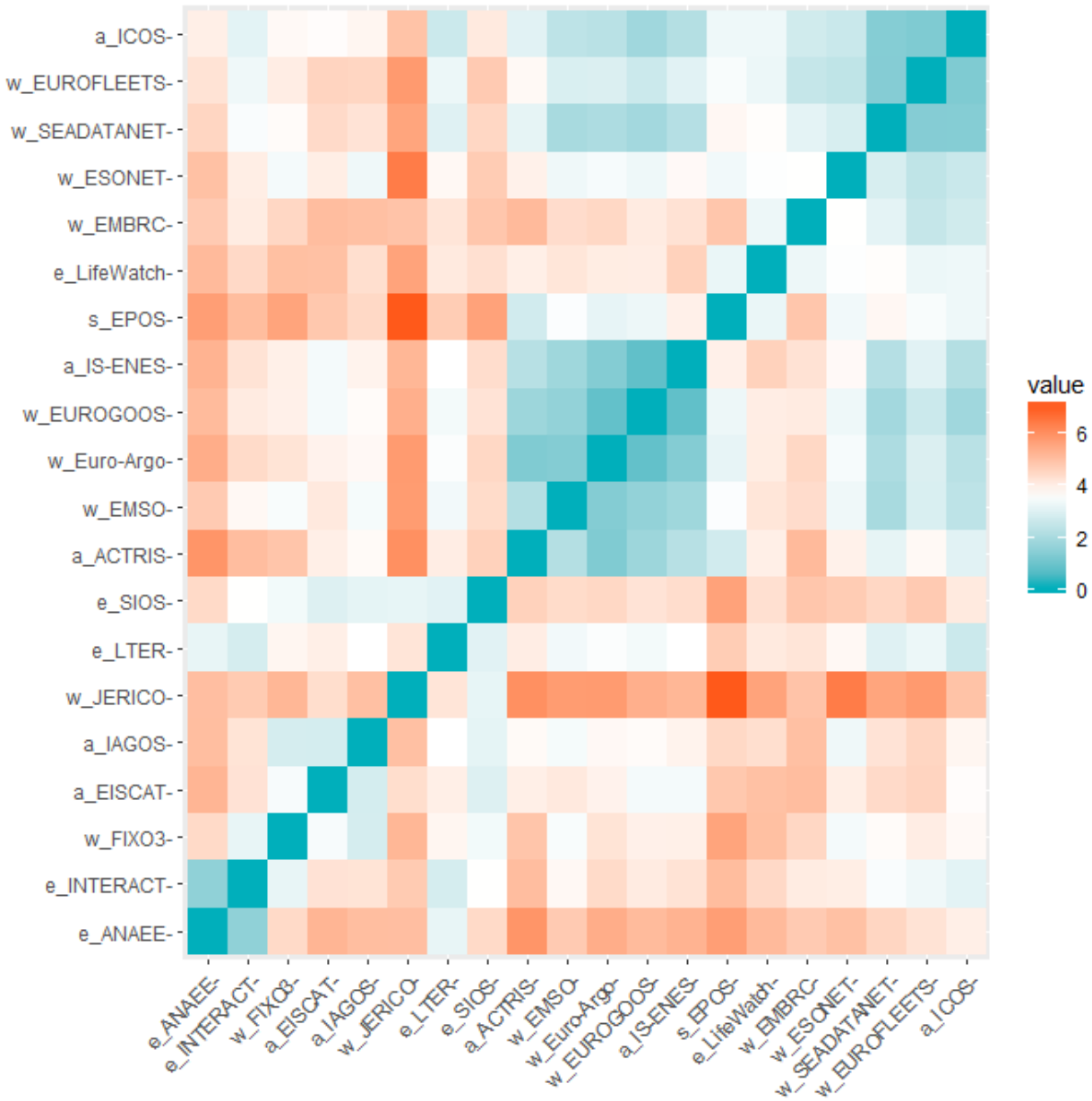


Figure 41: Distance matrix visualizing the standardized mean relevance (%) of only the US NRC Grand Challenges (NRC1-NRC8) for different research infrastructures (RI): ACTRIS (n=2), ANAEE (n=2), EISCAT_3D (n=2), EMBRC (n=1), EMSO (n=1), EPOS (n=4), ESONET VI (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), EUROGOOS (n=2), FIXO3 (n=1), IAGOS (n=3), ICOS (n=2), INTERACT (n=2), IS-ENES2 (n=1), JERICO (n=2), LifeWatch (n=2), LTER (n=6), SEADATANET (n=1), SIOS (n=1). Distance matrix was computed by the Euclidean distance using the R package 'factoextra' version 1.0.5.

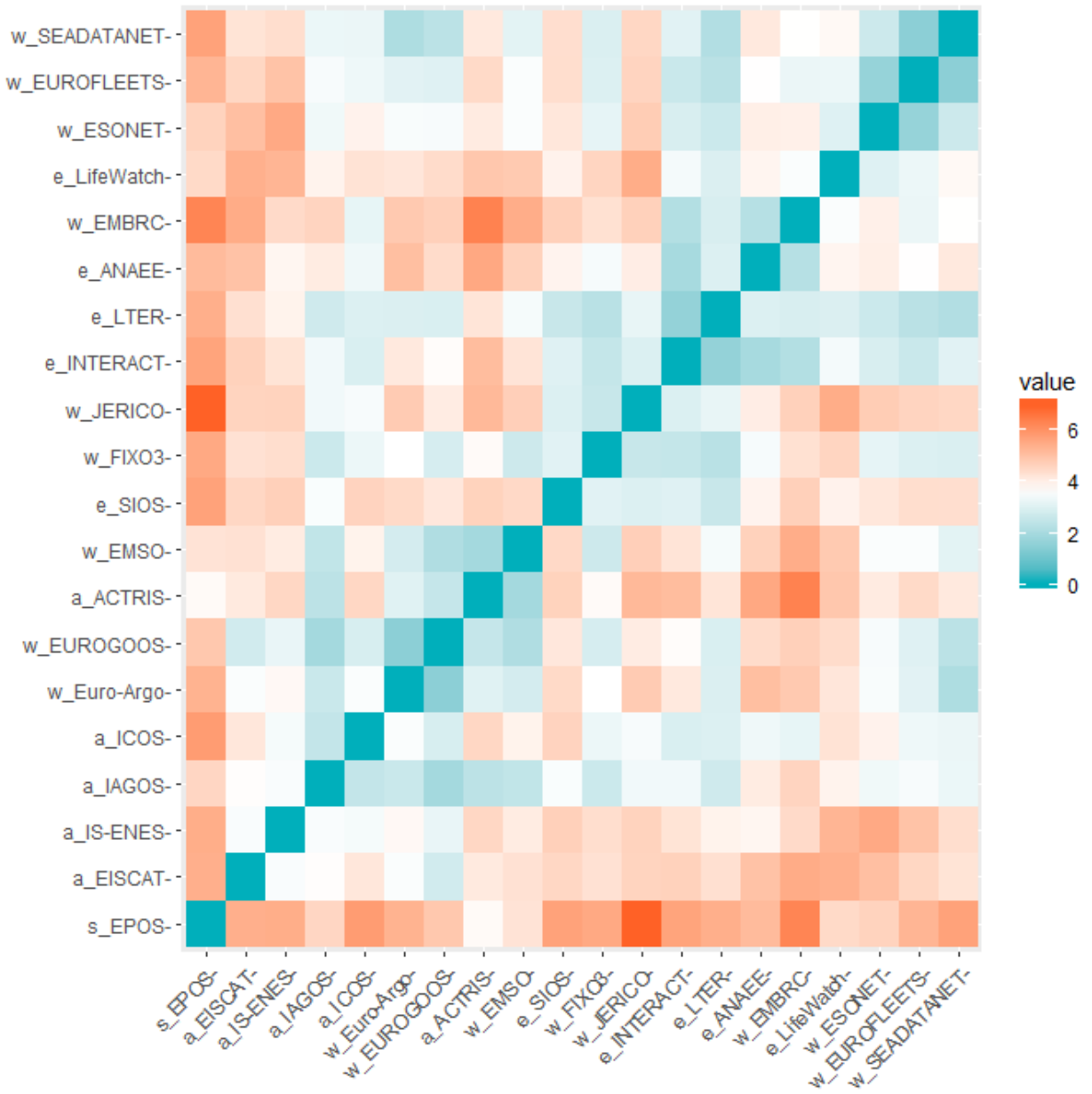


Figure 42: Distance matrix visualizing the standardized mean relevance (%) of the priority GCs (EC5-8, NRC1-4) for different research infrastructures (RI): ACTRIS (n=2), ANAEE (n=2), EISCAT_3D (n=2), EMBRC (n=1), EMSO (n=1), EPOS (n=4), ESONET VI (n=1), Euro-Argo (n=2), EUROFLEETS2 (n=1), EUROGOOS (n=2), FIXO3 (n=1), IAGOS (n=3), ICOS (n=2), INTERACT (n=2), IS-ENES2 (n=1), JERICO (n=2), LifeWatch (n=2), LTER (n=6), SEADATANET (n=1), SIOS (n=1). Distance matrix was computed by the Euclidean distance using the R package 'factoextra' version 1.0.5.

The Cluster Analysis (Figure 43) underpins special niches or profiles already identified and explained before (EPOS, JERICO, AnaEE).

The analysis resulted in four clusters and one RI (JERICO) being isolated in the fifth cluster #2. Since all RI have high values in EC7 (Climate: Develop global environmental observation and information systems), this GC is probably not driving the clustering. The separation along the x-Axis seems to distinguigh between high values EC8 (Security: Enhance the resilience of society against natural and man-made disasters) as secondary GC creating the purple cluster #5 with EPOS, EMSO (earthquakes, tsunamis) and ACTRIS (air pollution, volcano ashes) on the left side and EC5 (EC5 Climate: Environmental protection, sustainable management of nat. resources, water, biodiversity and ecosystems) on the right, resulting in the green cluster #3 connecting eLTER, AnaEE, FixO3 and SIOS all comprising a general and ecosystem-related approach. Other infrastructures may not be distinguished along this dualism resulting in two central clusters that are separating along the y-Axis. Here a first explanation may be a stronger focus on biogechemical cycles (NRC1) in the upper red cluster #1 and on Biological Diversity and Ecosystem Functioning (NRC2) in the lower blue cluster #4.

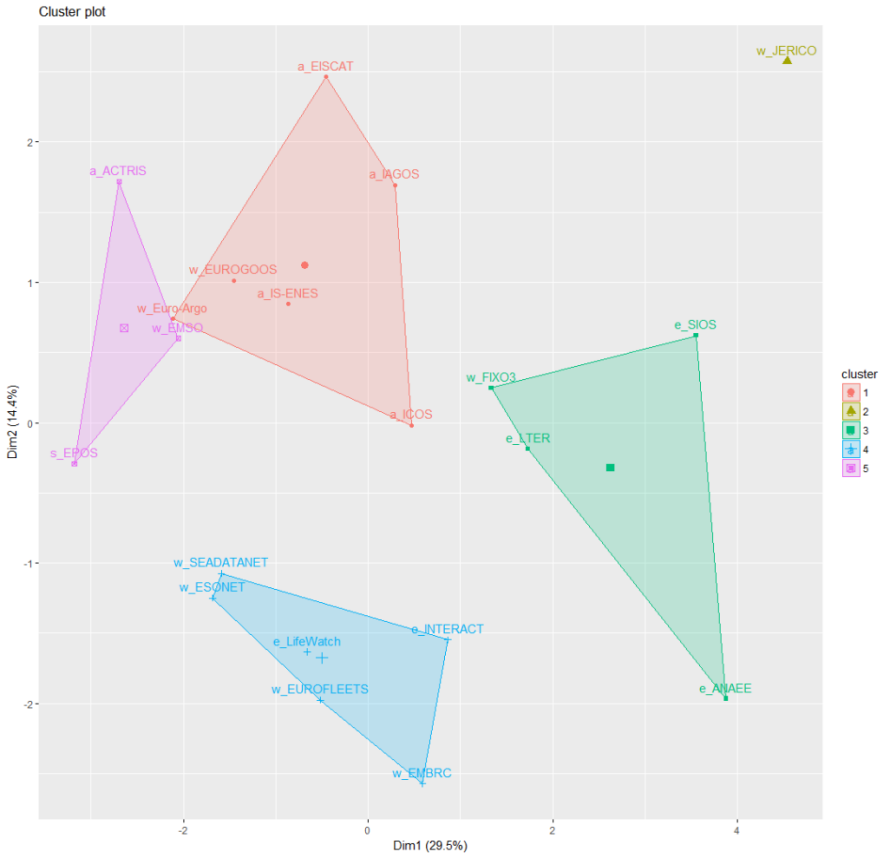


Figure 43: Cluster analysis based on k-means of the standardized mean relevance (%) of the European Grand Challenges (EC1- EC8) and the US NRC Grand Challenges (NRC1-NRC8) for all participating RIs. All analyses were performed by using the R software 3.4.1.

The central position of ICOS may show the limits of the approach of labelling bi- or multi-disciplinary RIs in one domain. Although ICOS is clustered with other atmospheric RIs such as IAGOS and EISCAT-3D it is positioned very closely to eLTER (Ecosystem) and FixO3 (Ocean). Generally, it is noteworthy that the clusters do not reflect the domains and with that open new pathways of cooperation e.g. towards common users and stakeholders. Examples could be common approaches between ACTRIS and EPOS, ICOS and EuroARGO, Lifewatch and EMBRC, or eLTER and SIOS.

4.1.7 Results from responses of highest granularity (level 3)

As indicated in chapter 3.5, we allowed survey participants to provide more detailed responses on focal Grand Challenges of their RIs (granularity level 3). They could suggest a "the rank one Grand Challenge" and a "rank two Grand Challenge" for their RI from either the EC or NRC Grand Challenges. Due to the facts, that (1) granularity level 3 was voluntary, (2) much of the response was by free texts, (3) the number of answers per RI varied, and (4) we did not receive answers from all RIs, the results cannot be used for comparative overviews. However, they contain a range of important information, - specifically in combination with the level 2 results and with respect to the status of RI and RI services development.

71% of the "rank one GCs" were chosen from the EC GCs and 29% from the NRC GCs. As for "rank two GCs", 40% belonged to EC GCs and 60% to NRC GCs. The ranking of GCs when only considering the "rank one" GCs complies with the granularity level 2 survey results (see Table 4) both for EC and NRC GCs (Table 5, Table 6) with EC7 and EC5 and NRC2, NRC1 and NRC3 in the respective top ranks.

Table 5: EC Grand Challenges of highest relevance for RIs as "rank one" and "rank two" Grand Challenges, when only two Grand Challenges could be chosen per RI.

Answer Options	Response Percent
EC7 Climate: Develop global environm. observation and information systems	43%
EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems	29%
EC8 Security: Enhance the resilience of society against natural and man-made disasters	10%
EC2 Food security: Forestry, marine and maritime and inland water research	7%
Other	11%

Table 6: NRC Grand Challenges of highest relevance for RIs as "rank one" and "rank two" Grand Challenges, when only two Grand Challenges could be chosen per RI.

Answer Options	Response Percent
NRC2: Biological Diversity and Ecosystem Functioning	50%
NRC1: Biogeochemical Cycles	21%
NRC3: Climate Variability	17%
NRC7: Land use dynamics	4%
Other	8%

A very important question was, which RI product or service was considered as the most decisive one for the previously chosen "rank one Grand Challenge", where data availability through standard services for analyses and scientific reports dominated clearly, underpinning the focus on supporting actual scientific research (). Interestingly however, the reported status of this main product or service was in only 31% "fully implemented" in the sense of immediate fitness for use, but for 52% partly existing and in 14% of all cases restricted to "finished concepts" ().

Table 7: Products or services of RIs of highest relevance for the reported "rank one Grand Challenge"

Answer Options	Response Percent	Response Count
Data available through standard services	45,2%	19
Analyses and scientific reports	21,4%	9
Data for use at the overall RI level	16,7%	7
Data for use at the level of individual teams/sites (distributed RIs)	11,9%	5
Formally declared sites/site network (infrastructure for TA)	4,8%	2
Policy papers	0,0%	0

Table 8: Status of products or services of RIs of highest relevance for the reported "rank one Grand Challenge".

Answer Options	Response Percent	Response Count
partly existing	partly existing	52,4%
fully implemented (could be shown/checked immediately)	fully implemented (could be shown/checked immediately)	31,0%
finished concept (e.g. for emerging RIs)	finished concept (e.g. for emerging RIs)	14,3%
planned	planned	2,4%

Respondents could also list (multiple choice) other important services and products supporting the work on the "rank one Grand Challenge" (Table 9). The answers reflect the wide range of activities and impacts of RIs, which explains their diverse response to GCs, which we found in many cases as shown in chapters 4.1.1 and 4.1.2. Again, only one third of these services and products were reported as "finished" (Table 10)

Table 9: Other products or services of RIs of high relevance for the reported "rank one Grand Challenge" in addition to the main product/service.

Answer Options	Response Percent	Response Count
Analyses and scientific reports	Analyses and scientific reports	71,4%
Data for use at the level of individual teams/sites (distributed RIs)	Data for use at the level of individual teams/sites (distributed RIs)	47,6%
Data for use at the overall RI level	Data for use at the overall RI level	42,9%
Data available through standard services	Data available through standard services	35,7%

Policy papers	Policy papers	21,4%
Policy papers	0,0%	0

Table 10: Status of "other products or services" of RIs of highest relevance for the reported "rank one Grand Challenge" in response to the question, if these products or services could immediately be demonstrated

Answer Options	Response Percent	Response Count
Yes	Yes	35,7%
Partly	Partly	57,1%
No	No	7,1%

4.2 Inclusion in the ENVRI RM

Research Infrastructures play a key role in the lifecycle of research data, services and other assets, providing security and access policies for e.g., the acquisition, curation, publication, processing and other application of research data. The ENVRI Reference model (RM) was developed within cluster projects since 2011 [2] to describe the main characteristics of environmental Research Infrastructures (ENVRIs) focusing on their lifecycle of research data.

The methodology applied for developing ENVRI RM was the decomposition of the system descriptions based on viewpoints. The model, based on the Open Distributed Processing (ODP) standard, ISO/IEC 10746-n [3] for modeling complex distributed systems, provides five perspectives from which to describe systems: *enterprise,* i.e., system scenarios, involved communities, roles and behaviors; *computation,* i.e., system interfaces and bindings between system components; *information*, i.e., data objects and schemas of the system; *engineering*, i.e., system middleware, engineering principles; and *technology*, i.e., technology standards and decisions.

This decomposition of complex systems by viewpoints has been proved to be a useful technique for managing the complexity and for providing information tailored to different kinds of stakeholders such as RI managers, architects or developers [7,8,9]. ENVRI RM adapted the standard to the specific needs of ENVRIs, e.g. by replacing the *enterprise* viewpoint with the *science* viewpoint. The current version is described in detail in the ENVRI wiki [3]. Figure 44 gives an overview of the viewpoints of the ENVRI RM.

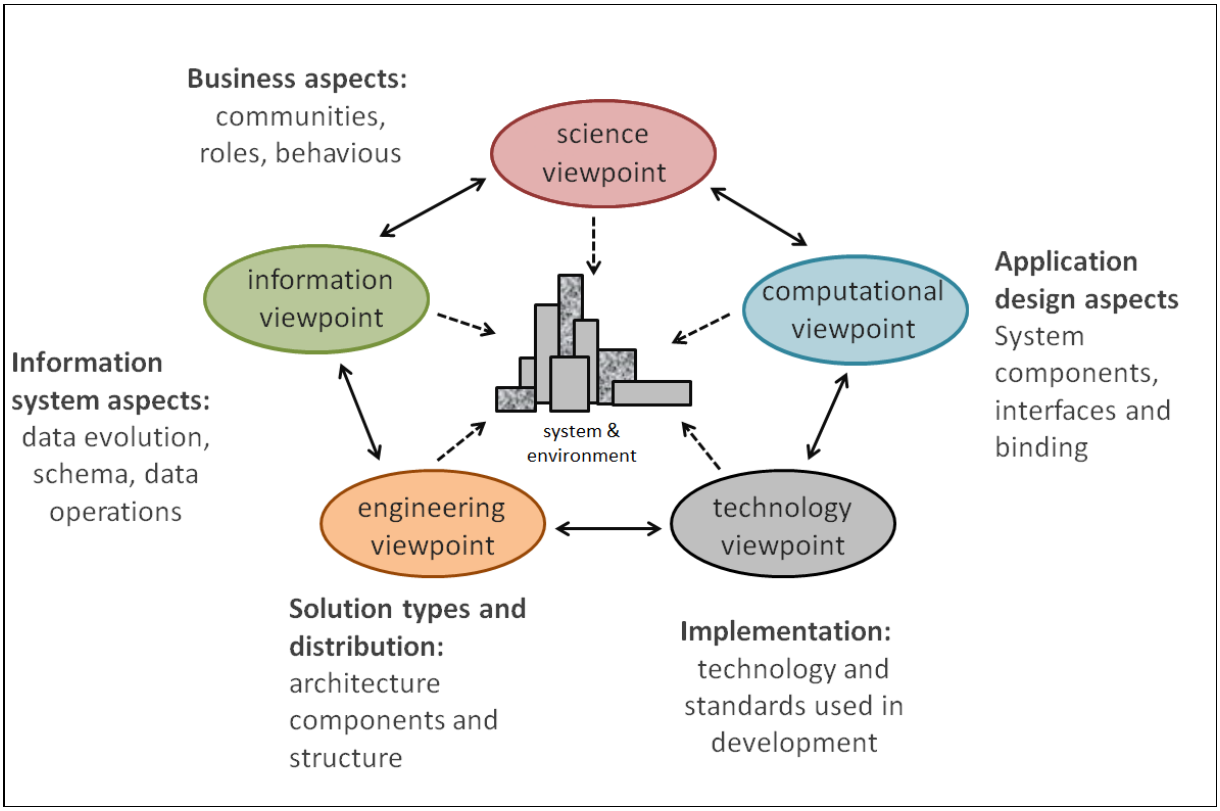


Figure 44: Viewpoints in the ENVRI RM.

ENVRI RM has been formally specified as an ontological framework called Open Information Linking for Environmental RIs (OIL-E) [4]. It represents the upper ontology for RI descriptions that can be used to contextualize different kinds of RI assets from architectural or operational perspectives. The ontology, including their instantiations, constitutes the ENVRI knowledge base (ENVRI KB) providing a repository for RI architectural

information. It is mainly conceived as a resource that can be queried and analyzed about technologies and standards used by RIs.

One of the objectives of Task 12.1 is the inclusion in the ENVRI RM of the representation of the Grand Challenges as well as of the RIs respective profile concerning the relevance of the RI scope for responding to Grand Challenges.

From a modeling point of view the Grand Challenges fall into the scope of the **science viewpoint.** The science viewpoint focuses on the institutional and social context of the domain in which the designed systems are intended to operate. This viewpoint concentrates on the objectives, processes, assets and policies that need to be supported by the research infrastructures being modeled. A research infrastructure is defined as a conglomeration of research resources and has communities as participants. The communities are collaborations which consists of a set of roles agreeing their objectives to achieve a stated scientific purpose by performing specific behaviors. Grand Challenges are modeled as objectives (compare with Figure 45).

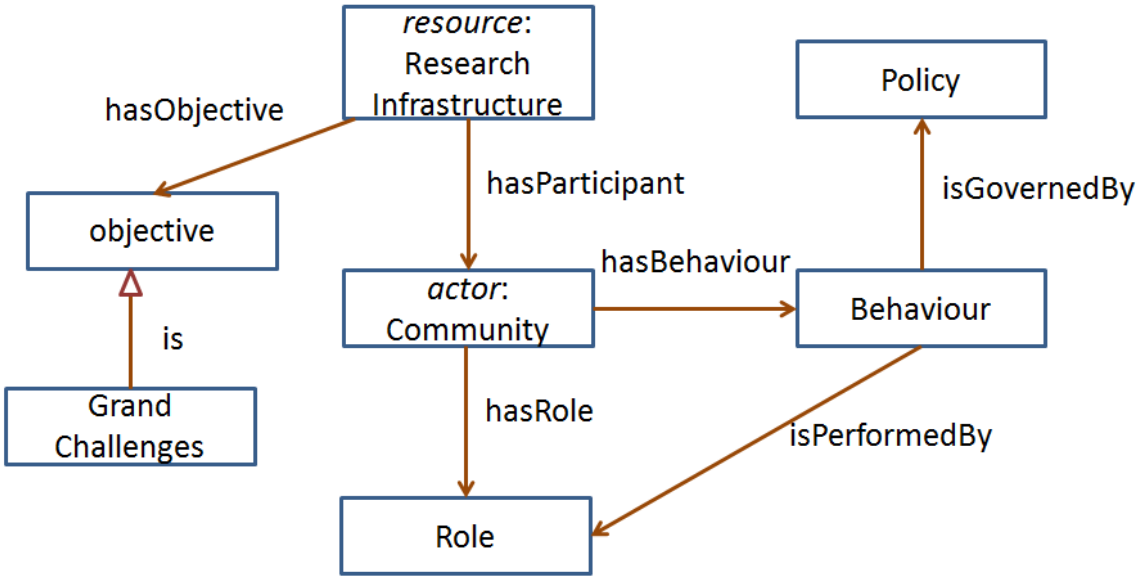


Figure 45: Science Viewpoint Objects and their relationships.

To be able to describe the ontological representation of these concepts within the ENVRI RM it is necessary to provide an overview of the main classes of the OIL-E ontology. The foundation of OIL-E is the *oil-base* ontology, which provides a set of generic concepts used in the construction of reference model archetypes. Derived from the most common elements observed in the ENVRI RM and distributed across the five ODP views the *envri-rm* ontology is the primary extension of *oil-base*.

4.2.1 Please consider the specific style types in the following description:

- **New classes, individuals, object properties and data properties introduced:**
- **Existing classes and *individuals,* object properties**

The oil-base ontology is composed of mainly two general classes:

1. **reference model classifier**: A categorization used to classify things present in a particular view of a system. An important class here is the **modeling viewpoint** which is used to assign entities to a specific viewpoint.

2. **reference model thing**: A thing that exists in the context of one or more views of a system. This is the main parent class for most entities of the ENVRI RM. Important subclasses are **reference object**, **reference attribute** and **reference activity**.

Both classes are used to incorporate the Grand Challenges concepts and their attribution to the RIs into the model. The extensions are included in the envri-rm ontology.

1. The class **Grand Challenges classification** is defined as a subclass of **reference model classifier**. This new class has three individuals:
   - *GC EC* – The European Commission's Grand Societal Challenges classification
   - GC NRC – The US National Research Council Grand Challenges in Environmental Sciences classification
   - *GC ICSU* – The ICSU Earth System Science for Global Sustainability Grand Challenges classification

Another subclass is defined under the **reference model classifier** hierarchy: **relevance class**. This class has 6 individuals, representing ordinal values, derived as mean values from originally 4 values (not at all, marginally, partly and fully):

- *R1*: not at all
- *R2*: marginally
- *R3*: marginally-partly
- *R4*: partly
- *R5*: partly-fully
- *R6*: fully

2. Under the class **reference model thing** there is the class **reference attribute** which is the parent class for **objective**. Under **objective** (a system's purpose), which is classified to be a science viewpoint thing, two new classes with following individuals are introduced:
   - **GC EC**: European Commission's Grand Societal Challenges
     - *EC1* Food security agro
     - *EC2* Food security - non-agro habitats & water
     - *EC3* Energy: New knowledge and technologies
     - *EC4* Climate: Resource and water efficient and CC resilient economy and society
     - *EC5* Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
     - *EC6* Climate: Fighting and adapting to CC
     - *EC7* Climate: Develop global environm. observation and information systems
     - *EC8* Security: Enhance the resilience of society against natural and man-made disasters
   - **GC NRC**: US National Research Council Grand Challenges
     - *NRC1* Biogeochemical Cycles
     - *NRC2* Biological Diversity and Ecosystem Functioning
     - *NRC3* Climate Variability
     - *NRC4* Hydrologic Forecasting

- *NRC5* Infectious Disease and the Environment
- *NRC6* Institutions and Resource Use
- *NRC7* Land-Use Dynamics
- *NRC8* Reinventing the Use of Materials

Under the class **Reference attribute** another class and subclass with 5 individuals have been added:

- Workflow:
  - ICSU workflow
    - Confining
    - Forecasting
    - Innovating
    - Observing
    - Responding

The individuals of Grand Challenge Classification are used to attribute the objectives and workflow to their specific classification systems. This is done by using and adapting the hasClassifier object property (see also Figure 46):

Reference Model thing hasClassifier reference model classifier.

GC EC hasClassifier value *GC EC*

GC NRC hasClassifier *value* *GC NRC*

GC ICSU hasClassifier value GC ICSU

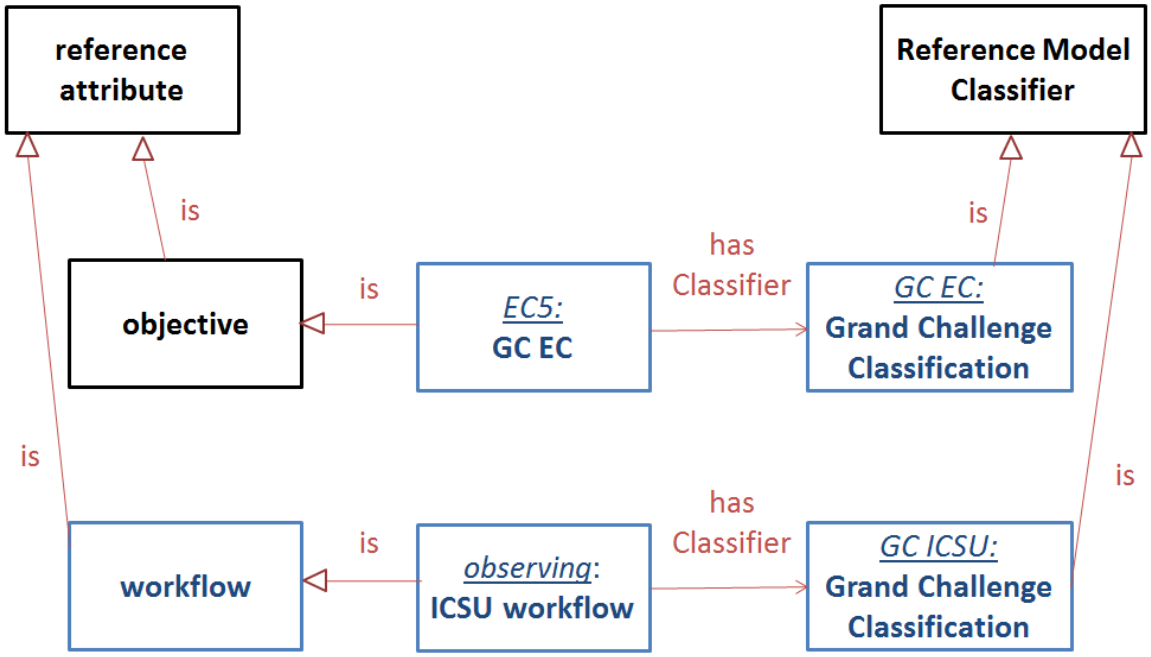


Figure 46: Grand Challenge Classification modeled in ENVRI RM.

The next set of extensions of the envri-rm ontology is used to model the RIs respective profile concerning the relevance of the RI scope for responding to Grand Challenges. There are two levels of specifications:

a. The relevance of the Grand Challenges for each RI scope
b. The relevance of the Grand Challenge for each RI scope linked to the RIs engagement in the scientific process chain (workflow)

For both relationship types it is necessary to introduce blank node classes and individuals. In OWL ontologies it is not possible to add attributes to binary relationships (object properties), e.g. it is not possible to specify that a RI has an objective GC EC5 with a specific relevance percentage. Blank nodes classes are used here to solve this problem, thus to allow the provision of additional information (see Figure 47.

Blank node classes and individuals are defined directly under the **Reference Model thing** class (in total 640 individuals for all combinations):

- blank
  - **blank objective** for specification of type a)
    - N1
    - N2
    - ..
    - N320
  - **blank objective workflow** for specification of type b)
    - N1001
    - N1002
    - ..
    - N1320

For the relations between the Research Infrastructure and the blank node classes two new object properties are introduced:

Research Infrastructure *hasObjectiveRelevance* blank objective

Research Infrastructure *hasObjectiveWorkflowRelevance* blank objective workflow

To model the relation between the blank nodes and the objectives the general hasObjective object property is used and adapted:

reference model thing hasObjective some objective

blank objective hasObjective some GC EC or GC NRC

blank objective workflow hasObjective *some* objective

To model the relation between the blank nodes and the ICSU workflow instances a new object property is introduced:

blank objective workflow *hasWorkflow* some ICSU workflow

To model the relation between the blank nodes and the relevance a new object property and a new data property are introduced:

blank objective workflow *hasRelevanceClass some* relevance class

blank objective *hasRelevance* some float (no object needed here, just a float value)

To illustrate the relationships an example for LTER is given in Figure 47:

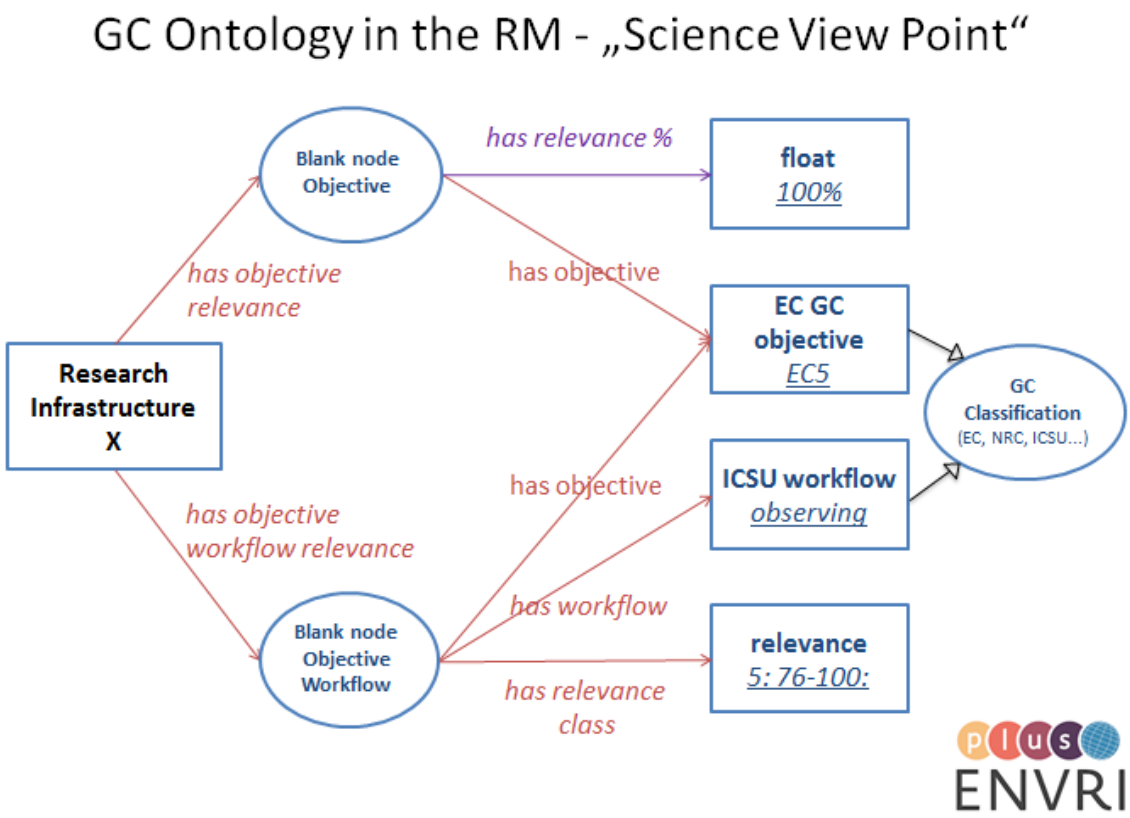


Figure 47: Grand Challenges in ENVRI RM modeled for LTER

As it can be seen, 7 relationships per RI (in total 20) and per Grand Challenge (in total 16) have to be created. This means that in total 2240 relationships have to be defined.

To support the process of the creation of the needed individuals and relationships a Jupiter Notebook script has been developed. It requires a Yaml file with a few values per RIs to be able to create triples (instances) for the ENVRI Knowledge Base (see Figure 48).

```yaml
---
infrastructure: LTER
objective: EC5
relevance: 100
relevanceClass: R5
workflow: observing
---
infrastructure: LTER
objective: EC6
relevance: 35
relevanceClass: R4
workflow: observing
```

```rdf
@prefix ns1: <http://www.oil-e.net/ontology/envri-rm.owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

ns1:LTER a ns1:ResearchInfrastructure ;
    ns1:hasObjectiveWorkflowRelevance [ ns1:hasObjective ns1:EC5 ;
            ns1:hasRelevanceClass "26-50" ;
            ns1:hasWorkflow ns1:observing ],
```

Figure 48: Yaml file and RDF output for the ENVRI KB

4.2.2 New classes, individuals, object properties and data properties introduced:

(Existing **classes** and *individuals,* object properties*)*

Reference model classifier -> GC Grand Challenges Classification

-> GC EC

-> *GC NRC*

-> ICSU Workflow

-> observing

-> forecasting

-> confining

-> responding

-> innovating

-> Relevance

-> 1: 0%

-> 2: 1-25%

-> 3: 26-50%

-> 4: 51-75%

-> 5: 76%-99%

-> 6: 100%

Reference Attribute -> Objective

-> GC EC

-> EC1

-> EC2

-> EC3

-> EC4

-> EC5

-> EC6

-> EC7

-> EC8

-> GC NRC

-> NRC1

-> NRC2

-> NRC3

-> NRC4

-> NRC5

-> NRC6

-> NRC7

-> NRC8

Reference Model Thing

-> blank node thing

-> blank objective

-> blank objective workflow

has relevance -> domain: **reference model thing**, range: **relevance**

has workflow -> domain: reference model thing, range: ICSU workflow

has objective relevance -> domain: **reference object**, range: **blank objective**

has objective workflow relevance -> domain: **reference object**, range: **blank objective workflow**

has maturity -> domain: **blank objective,** range: float

Newly introduced relations

GC EC has classifier value GC EC

GC EC has classifier value GC NRC

research Infrastructure *has objective relevance some* blank objective

research Infrastructure *has objective workflow relevance some* blank objective workflow

blank objective *has objective* some objective

blank objective *has maturity* some float

blank objective workflow has objective *some* objective

blank objective workflow *has relevance some* relevance

blank objective workflow *has workflow some* ICSU workflow

4.3 Economic impact assessment of environmental research infrastructures

A further aspect in the assessment of societal relevance of research and research infrastructures is what is usually expressed as 'economic impact'. Research projects, RI business plans, and also the daily continuous research activity of the scientific and academic community are challenged to produce evidence of their contribution to economic growth, ideally by some directly measurable indicators. From an RI perspective, and in particular from our perspective within ENVRIplus, attempts to address this challenge so far are not really satisfactory. As part of the work in task 12.1, a pilot study was now undertaken to review a possible methodology to assess economic impact based on the categories 'upstream', 'downstream' and 'feedback' and the relevant processes in the research life-cycle and their interconnections. Upstream impacts are related to the commercial relationship between environmental RIs and equipment suppliers on one hand and RI developers and operators on the other. Downstream impacts relate to the supply of data, products, and value-added services by RIs to users (consumers). Feedback or response impacts then consider the demand on RI outputs and performance based on societal needs e.g. in the mitigation of natural hazard based risks to society.

Annex 6.3 presents a case study for the Euro-Argo RI that addresses how the relevant information to assess downstream, upstream and feedback impact can be collected and identifies challenges and potentials for future developments. One particular challenge highlighted is the tight interconnection of commercial and non-commercial (private sector and public sector) activities that many environmental RIs find themselves in, which does not allow for an easy and clear definition of generally applicable performance assessment measures. A further problem lies in identifying the correlation of RI output indicators to product demands. The final conclusion of the study is that in order to move towards trustworthy and comprehensive economic impact assessment of RIs more experience with assessment methods is needed as well as more (open) data on the economic interactions of RIs.

5 Conclusions and recommendations

The results of this study provide each participating Research Infrastructure with an indicative "Grand Challenges profile", specifying its role in response to three common Grand Challenge classifications and supporting RI-RI comparisons. Overall, the results reflect the gradient across RIs in terms of multiple purposes and disciplinary complexity from solid earth to atmosphere, hydrosphere and ecosystems incl. biodiversity.

The assessment of the European environmental RIs in the here developed ENVRIplus GC Matrix approach provides a well differentiated view of the relevance of the different RIs. The focal role of the environmental RIs collaborating in ENVRIplus is to observe the environment and contribute to the forecasting of environmental change.

- Closer inspection of the – at first partly random – results beyond this clear message, reveals a surprising depth of insight in the RIs' characteristics, and allows to ascribe each RI clearly visible roles in the context of addressing the main societal challenges. The decision to not establish a proprietary ENVRIplus set of Grand Challenges from within the partner RIs (that we would naturally then address comprehensively) but rather to accept the GC systems developed within larger socio-political contexts, and to dare our self-assessment against those externally defined priorities, has shown its worth. Not only does the resulting assessment provide an objective view that can be more easily defended towards external stakeholders, it also serves to refine and delimit the duties and responsibilities of environmental RIs in a collaborative societal process.
-

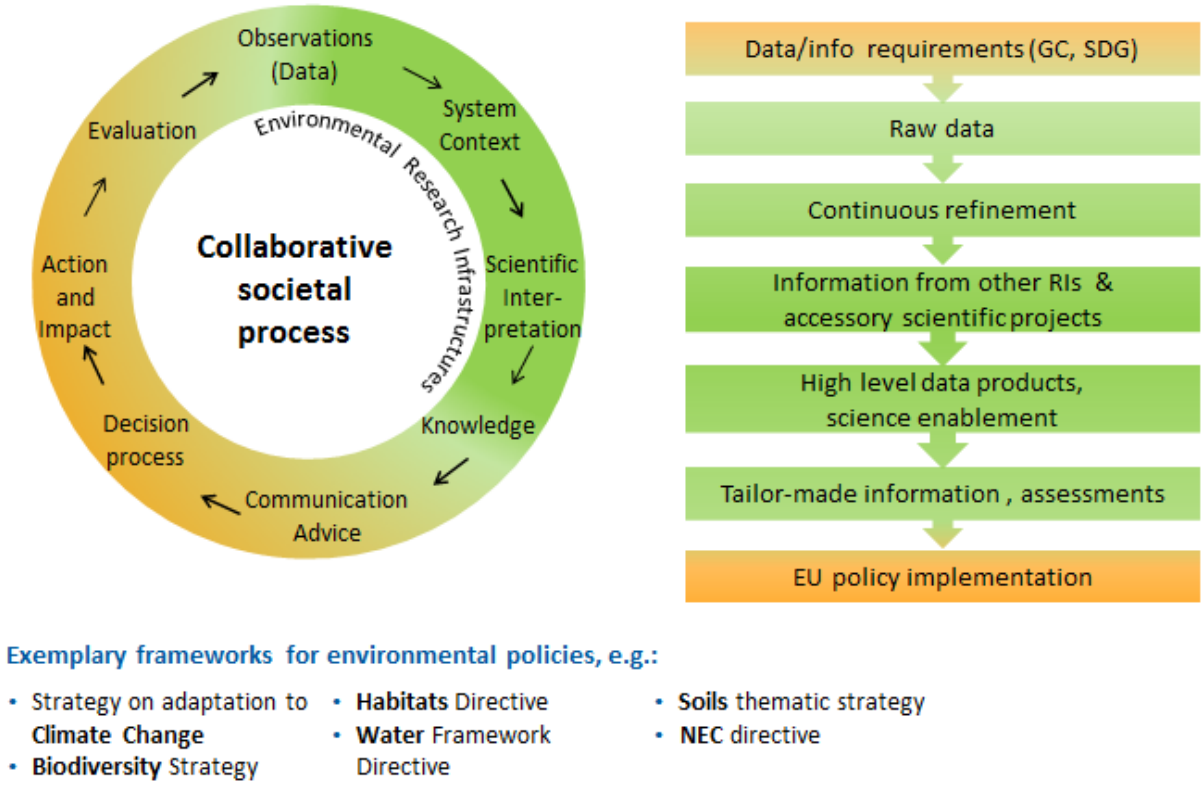


Figure 49: Environmental RIs in a collaborative societal process (source: Mirtl et al. 2019)

Recommendations

- We encourage the broad use of the study´s results, which can be detailed on request.

- The acknowledgement of environmental RIs focal functional niches in the overall societal context can help avoiding overselling pressure and thereby increase cost efficiency
- The approach should be extended to other and emerging classifications
- From a stakeholder perspective, the broader view on the environmental RIs overall service portfolio can contribute to
  - supporting the necessity of a diverse environmental RIs landscape
  - specifying complementarities and strategic alignment options
  - facilitating technical collaboration, co-location

5.1 Deviation from the description of action

The title of this deliverable in the description of action is "Report describing the relation between challenges of human systems and environmental information generated in RIs as documented module of the ENVRIPLUS Reference Model updated based on the experiences from Tasks 33 and 34". However, it was decided to change the title to better reflect the work carried out and the results obtained. Moreover, the original deliverable title was reffering to Tasks 33 and 34, the tasks that no longer existed in the description of action. They were replaced by Task 12.2 and 12.3 (changing the numbering of the tasks was required by European Commission at the proposal stage).

6 Annexes

6.1 Online Survey

Link of the survey as long as SurveyMonkey fee is paid and the survey is active:

First page of the survey:

ENVRI+ WP 12.1: Environmental RIs response to Grand Challenges

Introduction

What one needs to know about the survey:

- ENVRI+ is supposed to check, how it´s RIs relate to "Grand Challenges" (GC).
- A range of diverse GC definitions and classifications already exists.
- Our basic decision was, NOT to invent a new Grand Challenge classification
- But to use existing classifications in order to explain "RI relevance for GCs" in "stakeholders language".
- After a pre-screening we checked 4 GC classifications in detail (exercise at the ENVRI+ start-up).
- Three of them were relevant: EC, NAS/NRC, ICSU
- Two of them describe two different user viewpoints
  - EC: the societal point of view (EC Grand Challenges; selection by WP 12 team)
  - NAS/NRC: the scientific point of view (NRC Grand Challenges in Environmental Sciences, US National Research Council)
- One of them describes a high level workflow
  - observe - forecast - confine - respond - innovate (see explanation at first occurence before question 6)
- For each Grand Challenge classificatoin (EC, NAS/NRC) the work flow applies
- RIs respond do selected GCs, but also to explicit parts of the work flow
- The resulting cross-matrix (see graph below) was used as basis for this Survey

ENVRI+ Grand Challenges Matrix

GC classification				ICSU Scientific Grand Challenges identified to address global				
				Observing	Forecasting	Confining	Responding	Innovating
European Commission's Grand Challenges	EC	Food security	Food security					
	EC	Food security	Forestry, marine and maritime and inland water research					
	EC	Energy	New knowledge and technologies					
	EC	Climate & res.effic.	Resource and water efficient and CC resilient economy and society					
	EC	Climate & res.effic.	Env. protection, sustainable management of nat resources, water, biodiv & ecosystems		FOR EACH CROSS-SECTION THE SCOPE OF RESEARCH INFRASTRUCTURES CAN BE CHECKED			
	EC	Climate & res.effic.	Fighting and adapting to CC					
	EC	Climate & res.effic.	Develop global environm. observation and information systems					
	EC	Security	Enhance the resilience of society against natural and man-made disasters					
US NAS - Grand Challenges in Environmental Sciences	NAS	1	Biogeochemical Cycles					
	NAS	2	Biological Diversity and Ecosystem Functioning					
	NAS	3	Climate Variability					
	NAS	4	Hydrologic Forecasting					
	NAS	5	Infectious Disease and the Environment					
	NAS	6	Institutions and Resource Use					
	NAS	7	Land-Use Dynamics					
	NAS	8	Reinventing the Use of Materials					

Answering the questionnaire is voluntary. You have been selected to answer the questionnaire as your professional capacity as the representative of the RI you are working with. We only ask for some basic personal data in order to enable proper assignment of the provided information to the ENVRI+ RIs and your role within your RI.

All data will be stored securely on servers of the Environment Agency Austria (Task 12.1 lead) and will only be used within the framework of the ENVRIplus project. The questionnaire technical results and conclusions deducted from the results can be published within the ENVRIplus project deliverables, reports and documentation, however no personal information will be published in any form. All questionnaire answers will be deleted at the end of the ENVRIplus project. If you leave your contact information, you can also request to be informed on the reports and documents generated from the information collected in this questionnaire.

6.2 Detailed results of the GC on-line survey (granularity level 3)

For at least ONE Grand Challenge participants were asked to specify their RI´s contribution in more detail. This consisted in the following steps:

1) Selection of the RANK ONE EC Grand Challenge OR the RANK ONE NRC Grand Challenge for the RI

2) Possible selection of a related EC or NRC Grand Challenge

3) Selection of the main ICSU workflow step(s) the RI contributes to concerning the selected RANK ONE Grand Challenge

4) Specification of the RI contributions by some attributes

5) Free text to describe this contribution in more detail

Main outcomes are summarized in chapter 4.1.7. This annex presents the original answers alphabetically sorted by RIs.

ACTRIS

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Analyses and scientific reports • Policy papers
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The Research Infrastructure ACTRIS is the pan-European initiative that consolidates strategies amongst European partners for observations of aerosols, clouds, and trace gases. The infrastructure is unique in providing the 4D-

	variability of clouds and of the physical, optical and chemical properties of short-lived atmospheric species, in particular those involved in climate forcing. Proper investigation of the issues identified in ACTRIS requires the polling of knowledge and expertise that can only be achieved at the European scale. ACTRIS brings a unique expertise in the fields of metrology of aerosols, clouds and trace gases as well as data analysis and modeling, data management and delivery procedures suitable for improving current observational capacity. The data products resulting from the integration of expertise will facilitate and enhance scientific exchange with user communities working on models, satellite retrievals, and analysis and forecast systems. ACTRIS consolidates and strengthens services offered to a very wide community of users, responding to a demand that is regularly increasing.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Data available through standard services • Analyses and scientific reports • Policy papers • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes

* Describe the MAIN product/service with respect to the indicated Grand Challenge	ACTRIS contributes in resolving the uncertainties in climate and earth system models towards the development of sustainable solutions for responding to environmental challenges. ACTRIS benefits European society in several ways. ACTRIS provides unique data and understanding of atmospheric processes related to air pollution, aerosol-cloud interactions, and climate change. This data and knowledge allows society to better identify atmospheric hazards, climate change and health issues supporting society in its response and mitigation policies. For example, the Eyjafjallajökull volcanic eruption in 2010 demonstrated the unique capability of the ACTRIS community to rapidly provide relevant information on the state of the atmosphere for civil aviation authorities.

ANAEE

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	planned
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level • Analyses and scientific reports • Policy papers
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Ability to forecast the effects of anthropogenic impact (climate change) on state and functioning of natural and managed ecosystems, leading to improved understanding of consequences and potential solutions to confine the problems.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC1 Food security: Food security
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	finished concept (e.g. for emerging RIs)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Test yield under different climatic (atmospheric / CO2) and land use scenarios For scientists offer experimental platforms for stakeholders offer outreach products (based on work done by RI users)

EISCAT_3D

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC1 Food security: Food security
* NRC Grand Challenge	NRC4: Hydrologic Forecasting
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the level of individual teams/sites (distributed RIs)
* Status of the MAIN product/service	finished concept (e.g. for emerging RIs)

* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level
	Data available through standard services
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	No
* Describe the MAIN product/service with respect to the indicated Grand Challenge	

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The present EISCAT systems produce obervational data of the ionospheric conditions above northernmost Europe

EMBRC

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Responding
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data available through standard services • Analyses and scientific reports • Policy papers • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	EMBRC will respond by providing the necessary tools for fundamental and applied research, as well as the necessary monitoring data, either off site or on site at over 20 marine sites across Europe.

EMSO

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing

* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Data

EPOS

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC8 Security: Enhance the resilience of society against natural and man-made disasters
* NRC Grand Challenge	None
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly

* Describe the MAIN product/service with respect to the indicated Grand Challenge	Rapid public earthquake information and massive crowdsourcing for improved situation awareness

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC8 Security: Enhance the resilience of society against natural and man-made disasters
* NRC Grand Challenge	None
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	EPOS: Earth Plate Observing System, as its name says: aims to monitor Earth seismologic parameters in order to prevent from natural hasards.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC8 Security: Enhance the resilience of society against natural and man-made disasters
* NRC Grand Challenge	None
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing

* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Observation of the earth (seismology, geodesy...) for natural hazards assessment and resilience

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC8 Security: Enhance the resilience of society against natural and man-made disasters
* NRC Grand Challenge	None
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data available through standard services • Analyses and scientific reports • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly

* Describe the MAIN product/service with respect to the indicated Grand Challenge	Geophysical observation data (products and services) relevant for geohazards

ESONET VI

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC2 Food security: Forestry, marine and maritime and inland water research
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the level of individual teams/sites (distributed RIs)
* Status of the MAIN product/service	finished concept (e.g. for emerging RIs)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The main data products are taken over step by step by EMSO ERIC. exemple: http://www.emso-fr.org/EMSO-France Remaining services (on relation to exploitation of mineral ressources, fisheries, monitoring of marine environment according to Marine Strategy Framework Directive, marine renewable energy, oil and gas energy , innovative material,...) are planned to be integrated during the first 3 years of EMSO ERIC.

Euro-Argo

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing

* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Analyses and scientific reports • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The Global Argo array data are availaible in Real-time (within 24hours) and delayed mode (within 1 to 2 years) from two global Data Centers located in France and USA . Climate Change indicators such Global heat Content trend are computed from such dataset at least on a yearly basis and made available to the community through the Copernicus Marine Service. Morevover such data are essential data for assimilation in Forecasting operational ocenography models and also for re-analysis activities .

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist	Yes

(could be shown/checked immediately)	
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The Euro-Argo collects physical (Temperature Salinity current) and biogeochemical (Oxygene , Chlorophyl, bacscatter, Radiance and Nitrate . Ph and PCO2 are targeted variables) using autonomous profiling floats that presently sample the first 2000m of the water colum . Technology is evolving to go deeper (4000 to 6000 m) and also to operate is parilly ice covered areas. The goal of the Argo and its European component Euro-Argo is to be sustained for a long period to be able to fulfill Climate Change requirement and already result can be shown especially because Argo is providng measurement in areas that have never been sampled. Morover the Argo Network is a key network for Ocean Monitoring and Forecasting System as they are the only in situ source for constraining the models at depth

EUROFLEETS2

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	• Analyses and scientific reports
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Cruise reports from the oceanographic vessel. (Several disciplines are concerned: physical oceanography, biogeochemistry,...) Nota Bene: Other associated data collections are not reflected in the first three Grand

	Challenges: sea floor geology, mapping, pelagic biology and benthic biology

EUROGOOS

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Marine physical and Biogeochemical data open and free

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level

* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Oceanographic data are routinely available for climate reporting purposes through portals such as CMEMS, EMODnet and SeaDataNet

FIXO3

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Data available through standard services • Analyses and scientific reports • Policy papers • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes

* Describe the MAIN product/service with respect to the indicated Grand Challenge	Oceanographic data: chemistry, physics, biogeochemistry, biology Standard services for open data access Transnational access for testing new technologies and regional experiments Best practices Contribution to GEO Research and development of new observing systems

IAGOS

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	IAGOS provides in situ atmospheric chemistry observations on a global scale. Data and metadata are or will be available through web services (OGC compliant, etc.)

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing

* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the level of individual teams/sites (distributed RIs)
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The European Research Infrastructure IAGOS (In-service Aircraft for a Global Observing System) operates a global-scale monitoring system for atmospheric trace gases, aerosols and clouds utilising the existing global civil aircraft. IAGOS is a major contributor to the in-situ component of the Copernicus Atmosphere Monitoring Service (CAMS), the successor to the Global Monitoring for the Environment and Security - Atmospheric Service, and is providing data for users in science, weather services and atmospherically relevant policy. IAGOS is unique in collecting regular in-situ observations of reactive gases, greenhouse gases and aerosol concentrations in the upper troposphere and lowermost stratosphere (UTLS) at high spatial resolution. It also provides routine vertical profiles of these species in the troposphere over continental sites or regions, many of which are undersampled by other networks or sampling studies, particularly in Africa, Southeast Asia and South America.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services

* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Database with longterm observations of atmospheric composition, aerosol and cloud particles on a global scale from commercial aircraft of internationally operating airlines.

ICOS

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Data available through standard services
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Providing high-accuracy long-term monitoring of greenhouse gases across domains, i.e. the ecosystem, the atmosphere, and the ocean

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Analyses and scientific reports • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	The first objective of ICOS is to build a single and coherent data set and to open it for effective access to facilitate research on GHG concentration, related emissions and natural sinks. Data are assimilated in biogeochemical and ecological process models. ICOS aims at establishing a reference standard for the future development of similar integrated and operative GHG observation networks also beyond Europe. The second objective is to provide information for understanding of regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. ICOS allows detecting changes in regional greenhouse gas fluxes, early warning of negative developments and the response of natural fluxes to extreme climate events.

INTERACT

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge

* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the overall RI level
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	INTERACT is working on standardising climate observations at 77 arctic research stations. Metadata about the stations and metadata about climate data observed at the stations are stored in the Network database. In combination with data on ecosystem functioning and biodiversity These data are an important data source for research studying the relation between climate variability and change and the resulting effects on the physical earth System and the ecosystems.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Formally declared sites/site network (infrastructure for TA)

* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Data available through standard services • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Research station metadata repository with description of facilities and environment of all (+78) field bases, coupled with a repository of research project metadata from the partner stations. Transnational Access (calls for physical access to research stations), Remote Access (calls for sample collection by research station staff - scientists need not visit the station) and Virtual Access (scientific data from research stations made available for researchers through website). A number of products to improve station management, research and monitoring efforts, data sharing, outreach and marketing, etc. of research stations. Some of these products will also provide input to address international science agendas, contribute to international scientific networks and feed into global/regional/national/local decision making via existing organisations.

IS-ENES2

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC6 Climate: Fighting and adapting to CC
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)

* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	IS-ENES2 provides European global and regional climate model results for WCRP international coordinated experiments through the Earth System Grid Federation distributed database.

JERICO

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC2 Food security: Forestry, marine and maritime and inland water research
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level • Analyses and scientific reports • Policy papers • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	European network providing operational services for the timely, continuous and sustainable delivery of high quality environmental data and information products related to marine environment in European coastal seas. Other objectives are: Support European coastal research communities, enable free and open access to data, enhance

	the readiness of new observing platform networks by increasing the performance of sensors, showcase of the adequacy of the so-developed observing technologies and strategies, propose a medium-term roadmap for coastal observatories through a permanent dialogue with stakeholders. JERICO will proceed towards the automated monitoring at high temporal and spatial resolution of wider areas, and towards new thematic fields including biodiversity. This trend is expected for the implementation of the Marine Strategy Framework Directive.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC4 Climate: Resource and water efficient and CC resilient economy and society
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	EU-wide interoperability of ocean observing systems already existing or in the process of development.

LifeWatch

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge

* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	None
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	No
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Provide virtual environments to integrate and process data for analysis and modeling VEs are based on user demands (dynamic environment)

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Forecasting
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Analyses and scientific reports • Policy papers
* Do these OTHER product(s)/service(s) already exist	Partly

(could be shown/checked immediately)	
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Virtual environments, including web services (existing or development service) supporting users to: - find, access and integrate data sources - find, access and asses analytical and modelling tools - combine selected tools and data in workflows - deploy virtual labs offering such ready-for-use services - publish and results

LTER

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	None
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data for use at the level of individual teams/sites (distributed RIs)
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Huge amount of datasets and time series describing the structure and functioning of ecosystems/biodiversity

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning

* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Analyses and scientific reports • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Detailed site-based long-term studies

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC2: Biological Diversity and Ecosystem Functioning
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	finished concept (e.g. for emerging RIs)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist	Partly

(could be shown/checked immediately)	
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Data on changes in biodiversity on the background of climate warming

The RANK ONE Grand Challenge is...	a NRC Grand Challlenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC1: Biogeochemical Cycles
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Formally declared sites/site network (infrastructure for TA)
* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Data available through standard services • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	LTER provides a global network of research sites in benchmark ecosystems, where integrated ecosystem monitoring (featuring a full system approach equally considering abiotic and biotic system components). At selected sites of proper size (LTSER regions) socio-ecological research is carried out, investigating Long-term human-Environment interactions, including Management practices. Shorter term projects can be embedded into a matrix of site-specific long-term data series. eLTER ESFRI forms the European contribution to the global network.

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs) • Data for use at the overall RI level • Analyses and scientific reports • Policy papers • Formally declared sites/site network (infrastructure for TA)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	DATA AVAILABLE AT THE WATERSHED SCALE FOR THE HYDROLOGIC AND WATER QUALITY SIMULATION TERRESTRIAL BIOLOGY SURVEYS SOIL STUDIES REGARDING SOIL FERTILITY

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC7: Land-Use Dynamics
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Analyses and scientific reports

* Status of the MAIN product/service	partly existing
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the level of individual teams/sites (distributed RIs)
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Partly
* Describe the MAIN product/service with respect to the indicated Grand Challenge	Combining hydrological and biogeophysical in situ research with earth observations in an arid environment; Transdisciplinary research combining socio-ecological research with natural sciences in the study of human-environment interactions and responses.

SEADATANET

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC7 Climate: Develop global environm. observation and information systems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	fully implemented (could be shown/checked immediately)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data available through standard services • Analyses and scientific reports
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	Yes
* Describe the MAIN product/service with respect to the indicated Grand Challenge	see website and sustainable infrastructure and enhancement to be started through SeaDataCloud

SIOS

The RANK ONE Grand Challenge is...	a EC Grand Challenge
* EC Grand Challenge	EC5 Climate: Env. protection, sustainable management of nat. resources, water, biodiv & ecosystems
* NRC Grand Challenge	NRC3: Climate Variability
* The MAIN step in the ICSU workflow supported by my RI in this MAIN GC is	Observing
* MAIN product or service of your RI for the selected key Grand Challenge (one choice)	Data available through standard services
* Status of the MAIN product/service	finished concept (e.g. for emerging RIs)
* OTHER product(s) or service(s) of your RI for the selected key Grand Challenge (multiple choice)	• Data for use at the overall RI level • Analyses and scientific reports • Policy papers
* Do these OTHER product(s)/service(s) already exist (could be shown/checked immediately)	No
* Describe the MAIN product/service with respect to the indicated Grand Challenge	vision of SIOS is to observe a specific region of Svalbard Archielago and sorruindings in a Earth System Science perspective Core activities will provide data useful to address key ESS scientific questions. These data will be put at disposal through services at the Knowledge center to all SIOS users and not only. Integration of the huge amount of information will able to develop new products to better assess climate change challenges.

6.3 Economic impact review of environmental research infrastructures

6.3.1 Objective

The decision to invest in an ENV RI development project depends on its expected economic value. This value is frequently assessed against a cost-benefit analysis including different components: a) RI development costs; b) benefits gained from improving environment forecasting capacity and avoiding damage costs for environment sensitive activities; c) other components related to the costs and benefits generated by the development project on the chain of equipment suppliers and on RI product users.

The present note focuses on these components and makes a survey of the assessment methods. These are exemplified by an ocean-related case study.

The economic impacts considered in this note can be classified into three categories:

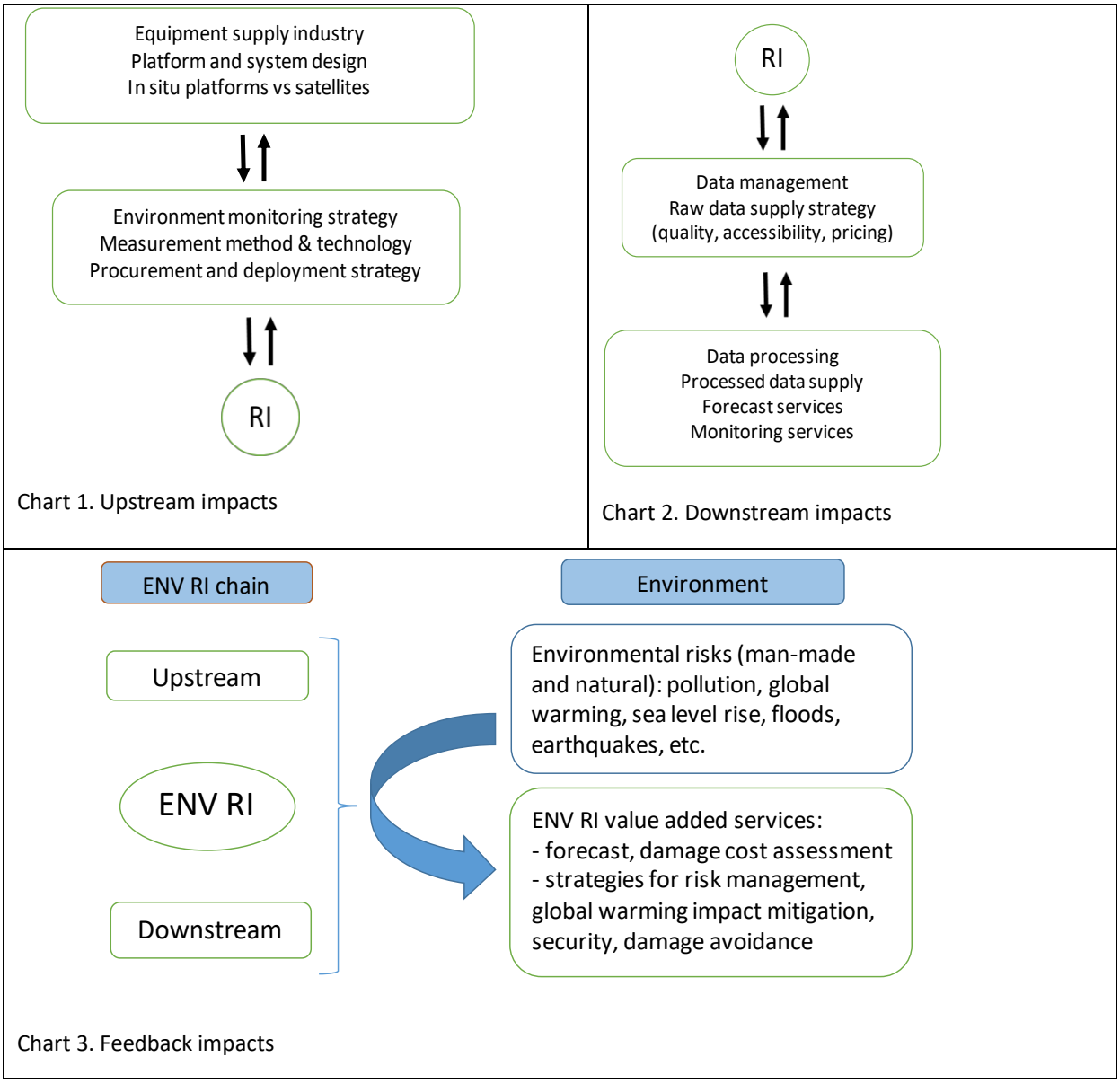
- Upstream impacts from ENV RI development on facility and equipment supply;
- Downstream impacts on ENV RIs' value added service supply to end users;
- Feedback impacts on environment in terms of damage mitigation and risk avoidance.

Upstream impacts are related to the commercial relationships between ENV RI facility and equipment suppliers (including design, manufacture and trade) on the one hand and RI developers and operators on the other. The economic impacts on suppliers are usually assessed in terms of turnover, employment, compensations, innovation and exports (chart 1).

Downstream impacts are related to the supply of primary data and processed products (e.g. forecast, environment monitoring data, and risk evaluation) and value-added services as generated by RI operators[1] and their customers. These different markets are driven by such factors as data product quality, pricing strategy and the size of demand. Data quality (a concept which receives increasing attention from statistical offices) is related to, for instance, accuracy, frequency, regularity, scope of the geographical coverage of data, and delay of access (chart 2).

Feedback impacts, or response impacts, involve the response to man-made and natural risks threatening environment sensitive activities. The feedback is that the development of ENV RIs is mainly motivated by environmental risks requiring more information and efficient forecast. Feedback impacts involve not only ENV RIs but also the supply chain from upstream equipment suppliers to the diversity of downstream value-added services (chart 3).

[1] RI operators can provide raw or processed data or other services to customers who generate value added by deriving new products and services from RIs' offer.



6.3.2 A case study: Euro-Argo

6.3.2.1 A relevant example of marine RI

Argo is an in-situ ocean observing system providing real-time and delayed mode observations at global scale. It develops an array of free-drifting profiling floats measuring temperature and salinity of waters from sea surface to -2,000 m. Euro-Argo, the European component of Argo, develops and maintains some 800 floats.

Euro-Argo cannot be analysed as a separate entity. It is complementary with from satellite born altimeters, and with other different sets of in-situ platforms and profilers such as CTDs (Conductivity-Temperature-Depth profilers) and XBTs (expendable bathythermographs).

It is part of an observation supply chain from primary data collection to processed data distribution, then to value added marine services for environment monitoring and security. The data acquisition chain of Argo, after satellite transmission, includes a data assembly segment. National Data Acquisition Centres (DACs) collect, quality-control, standardize, archive and distribute real- and delayed-time biological, chemical, physical and geophysical ocean

profiles from different types of instruments. These data, together with associated metadata, are provided to the two Global DACs (GDACs): US-GODAE, Monterey, California, and Coriolis, Brest, France.

Standardised and customized marine services are developed using a variety of processed marine data. In Europe, marine services can be funded by member states or the EC (i.e. organizations or networks of organizations, or observatories such as Copernicus Marine Services, Emodnet, EMSO and Mercator Ocean), or commercial consultancies.

Remarks:

- The present marine data market is recent and narrow: governmental influence remains important. Most data and service suppliers are either government-owned, or government- and EC- funded entities; these have a strong impact on the types of services and products delivered by downstream consultancies. Likewise, upstream equipment manufacturers and suppliers largely depend on government orders.
- The US-originating strategy of free-of-charge marine observation data products – to boost the competitiveness of downstream value-added services – is superseding alternative business models outside the US, notably in Europe (see Groupe interministeriel, 1995). On a narrow market such as that of marine data products, the current trend reinforces the role of government funding and of government-funded RIs in the supply chain.

6.3.2.1.1 Cost of Argo

The AtlantOS "Optimizing and Enhancing the Integrated Atlantic Ocean Observing System" project (H2020, 2015-2019) issued a report (Reilly et al., 2018) providing the estimated costs of a selection of ocean observing networks in the Atlantic, inter alia the costs of the Atlantic Argo array, of which Euro and US Argo floats. Despite data gaps, this report (tab. 1) provides valuable information on costs of in-situ observing networks over 2012-2016. Note that staff costs and research vessels and ships of opportunity costs have been excluded.

Table 1. Cost of Argo

	Euro Argo			AtlantOS area		US
	Core Euro-Argo (T&S)	Deep Argo*	BGC	Core Argo (T&S)	All Argo	
Number of floats deployed per annum, 2012-2016**		35	38	229		
Unit purchase cost (€)	14 280	30 000	85 000	15 890		17 500
Additional unit costs/year						
Testing and calibration (€)		300	300	300		
Logistics (€)		400	600	400		
Transmission (€)		1 920	1 440	1 440		
Total cost per annum (€)		1 124 900	3 337 160	4 128 870	8 590 930	
Workforce (FTE/year)***	22.63					

T&S: temperature and salinity profiler

BGC: biogeochemical profiler

*Arvor Deep Argo floats only. Apex floats excluded.

**Target annual deployment for Deep Argo and BGC floats.

***France includes co-ordination and management staff.

Source: Reilly et al. (2018).

6.3.2.2 Approach to the valuation of economic impacts: overview of methods

This section follows the classification presented above, and outlines an approach to the valuation of upstream, downstream and feedback impacts.

6.3.2.2.1 Assessment of upstream impacts

The question addressed in this section is: how to assess the quantitative impacts on suppliers from ENV-RI development, in terms of production, productivity and employment?

Classic statistical tools provide an answer to the question. They include the National Accounts and the Structural Business Statistics. Businesses are classified by principal activity, the set of activity classes being harmonized at international level. Using inquiries, SBS provide basic statistical data to develop National Accounts. This statistics enables it to infer estimates of the effect of demand from RIs on suppliers' incremental production and employment.

The assessment of upstream impacts starts from an analysis of demand from ENV RIs in terms of product and service purchases. These are then classified by type of products, according to the standard "Classification of Products by Activity" (CPA) of the European Communities, i.e. by the nature of goods and services and by "originating activity". The latter is defined based on another classification: the European classification of activities (NACE).

The above analysis of purchases allows assessing the impacts on each corresponding category of activities in terms of incremental turnover and employment.

Examples of such assessments are numerous in sector-based economic analysis. However, ENV RIs' requirements are much specialised in terms of equipment. One would expect the upstream impact analysis to differentiate between different categories of equipment supply, e.g. in-situ and satellite born instruments, platforms, electronics and associated services. Classic tools do not have a high enough resolution power to do this.

Alternative methods to get more detailed data require ad-hoc business inquiries on upstream suppliers.

6.3.2.2.2 Assessment of downstream impacts

In this section, the question is: how to assess the impacts of ENV RIs' performance in terms of primary data collection and of ocean (or atmosphere or environment) forecast?

The type of downstream impacts analysed in this section cannot be characterized by simple monetary indicators. Primary data collection performance impacts the performance of specialized forecast and monitoring services, and ultimately demand for data and forecast services. Performance has therefore to be considered at two stages:

a) At the stage of primary data collection: quality controlling and archiving.
b) At the stage of forecast modelling, using satellite observations. Forecast accuracy impacts demand for marine and other environmental value-added services.

6.3.3 Primary data collection performance

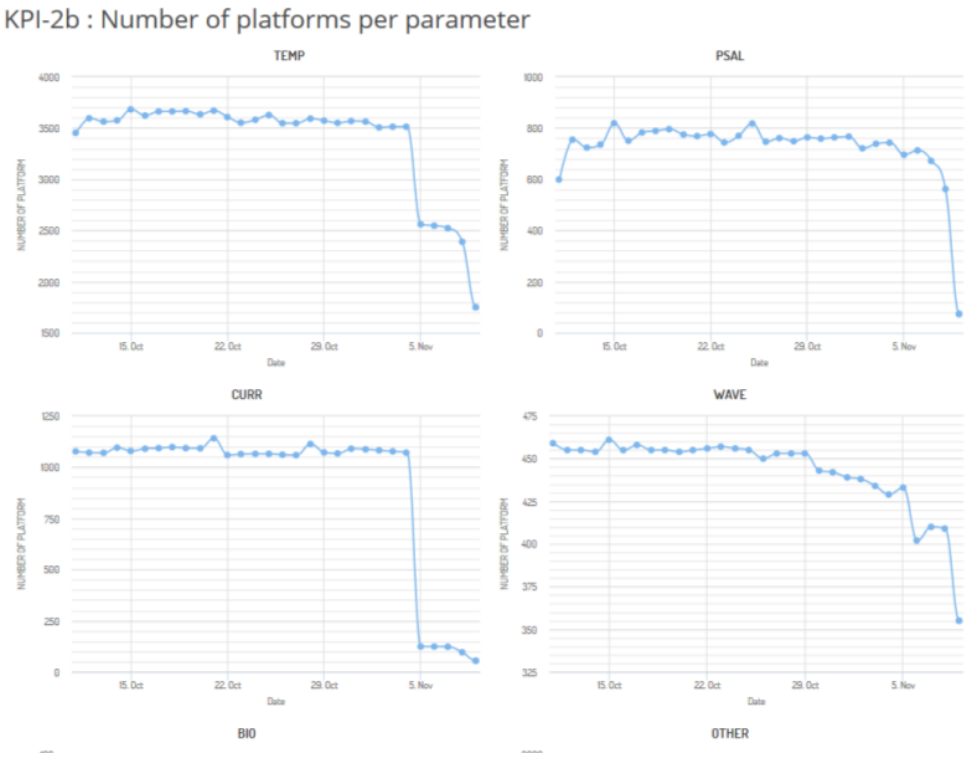
At the stage of data collection, quality control upgrades data series for potential users. For Argo, GDACs publish information on data performance using a metrics based on a set of key performance indicators (KPIs). These KPIs, as

described by Coriolis (Carval et al., 2015; Carval, Coatanean, 2016), shape a metrics of instruments performance against accuracy and punctuality criteria, and measure its impact on demand for observation data[2]. They include:

- Data generation delay (e.g. share of delayed data per time interval),
- Types and number of platforms (by type of sensors and by measured parameter),
- Accuracy of measurement (for temperature and salinity),
- Number of downloads and number of users.

But the "number of platforms per type" (chart 4), monitored since 2014, gives valuable indications on trends. Some KPIs are monthly, weekly or daily updated. In the future, longer series could permit to analyse correlations between supply (number of platforms, accuracy and delay) and demand (number of downloads).

Chart 4. Example of Coriolis KPIs



Source: Coriolis http://www.ifremer.fr/co/co05010507/KPI

[2] Other KPIs for Argo are generated by e.g. the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), an intergovernmental body in charge of, inter alia, co-ordinating the WMO Marine Meteorology and Oceanography Programmes. JCOMM's "in-situ Observation Programme Support Centre" (JCOMMOPS) monitors, and provides metrics for, a range of in-situ observing systems, of which Argo. Indicators include the array (activity, density, intensity), data flows (delivery, sensor metadata quality, timeliness) and national diversity.

6.3.4 Data analysis and forecast: observation experiments

The assessment of the performance of ocean analysis and forecast focuses on real time in-situ and satellite observations as incorporated in ocean circulation models. Forecast accuracy is critical for ocean monitoring and value-added services, in order to improve forecasting techniques and the design of observing systems.

Among the different types of experiments conducted to assess forecast accuracy and measure forecast errors, "observing system experiments" (OSEs) have become a common method. They serve to assess the impacts of observing systems on RIs' forecasting capabilities. The method consists in withholding a subset of observations on a specific data analysis and forecasting system and assessing the resulting degradation of forecast accuracy: this indirectly allows valuing the subset of information withheld. Conversely OSEs serve also to measure forecast improvement from using an additional subset of observations.

Several ocean OSEs were recently carried out in the framework of two research initiatives:

- GODAE OceanView – GOV (see Oke et al. 2015a, 2015b),
- E-AIMS – an FP7 project, 2013-2015 (see Rémy and Le Traon, 2015).

To assess forecast performance, traditional OSEs use the root mean square (RMS) of the difference between forecast and real-time observations to measure forecast accuracy. To give an example related to Argo: Turpin et al. (2016) assess the impact of Argo data assimilation on the short-term real-time analysis and forecast of sea surface temperature and salinity. The authors present the results of one-year OSEs conducted over 2012 using the "Mercator Ocean 0.25°" global ocean analysis and forecasting system. Experiments include the assimilation of:

- Satellite observations;
- Observations from all other-than-Argo in situ instruments;
- Observations from 100%, 50% and 0% of the Argo array.

The results show that the impacts on RMS for temperature and salinity are significant from sea surface to -2000 metres: the use of Argo data can lead to a 20 to 50% decrease in RMS for temperature on the 700-2000 m depth layer, and 30 to 65% for salinity. Lessons drawn from the OSE related literature include, inter alia, the following points:

- The use of Argo profiles has positive impacts on real time ocean analysis and forecast.
- Argo observations on sea water properties are critical to complement satellite altimetry.
- Results of OSEs depend on sea water parameters, the state of deployment of Argo, and the state of forecast models.
- Other types of OSEs than those described above have been performed. E.g. regional assessments (Oke et al., 2015b), and OSEs performed by JERICO on coastal observation systems (Wan et al., 2014), are critical to designing assessment methods on local observation system or local subsets of larger systems.

Remarks

The two approaches to assessing the performance of ocean observing systems' downstream segment are complementary: KPIs of in-situ observations assess the performance of observation data; OSEs relate to observation analysis and forecast. Combined together, they constitute a relevant metrics for ocean RIs' downstream impacts. To strengthen such complementarity, further steps are required:

- Longer time series will provide more knowledge on KPIs and observing experiments.
- Further insight is required on correlations between performance indicators and demand for observation and forecast products.

6.3.5 Feedback impacts

Feedback impacts involve the entire chain of activities upstream and downstream of Argo (combined with other ocean observing networks) as a response to environmental risks and uncertainty (hurricanes, oil spills, floods, etc.).

The analysis of the impacts of the entire ocean forecast product chain from primary data to marine value-added services involves the valuation of costs and benefits from improved ocean forecast. These benefits include the value of having more secure ocean sensitive activities. Such value is explained by the avoided costs arising from risk avoidance, as compared to investment and running costs.

Cost-benefit analysis (CBA) is a classic tool for valuing feedback impacts. CBAs on ocean and climate forecast often include a scenario based on advanced ocean services (monitoring and forecast) compared to a baseline scenario. Benefits include the avoided costs for ocean sensitive activities, coastal communities and marine ecosystem services.

6.3.6 Examples of CBAs on ocean forecast

Since the 1990s, several CBAs studied the economic impacts from the GOOS and the use of its products. Some studies, illustrative of the general approach, are mentioned below (tab. 2).

Table 2. Examples of CBAs on ocean forecast impacts

Study	Topic	Methodology	Results
Sassone, Weiher, 1997	Costs and benefits from TOGA project and ENSO observing system (EOS)	Impacts on US agriculture over 1995-2015. Sensitivity analysis using: -producers' and consumers' skill level (capacity for adapting to forecast), -future time horizon, -rate of acceptance of ENSO forecast, -annual future costs of EOS.	IRR = 13 to 26% Internal rate of return (IRR) based on expected farmers' profit and consumers' surplus for a 20-year period.
Solow et al., 1998	Benefits from better ENSO forecast on US agriculture through more efficient cropping.	Based on simulations: -Meteorology model for simulating ENSO forecast on temperature and precipitations. -Plant growth model for optimization of crop yield. -Economic model for assessment of expected impacts from crop strategies on crop product markets.	Expected producers' and consumers' annual surplus: $240 to 323 m as compared to ENSO forecast costs ~ $12.3m/year.
Kite-Powell, Colgan, 2001	Benefits from GoMOOS on marine activities in the Gulf of Maine	Review of Gulf of Maine commercial and non-commercial uses of GoM waters: -Key indicators per activity: operating costs/day, value added/day, willingness to pay for leisure, oil spill cost reduction. -Assumptions on avoided costs per activity from using ocean forecast and improving business management.	Annual potential benefits = sum of avoided costs per activity. Estimated at ~ $33 m. This is a lower bound as data are missing for several terms.
Cedre, Ifremer, 2009	Benefits from pilot tool for GMES. Case study: oil spill on France's Atlantic coast, December 1999	Review of local marine activities impacted by the oil spill (commercial activities only). -Estimates of turnover and employment per commercial activity. -Estimates of incremental avoided costs from more efficient mitigation of damage. -Estimates based on experience gained by Cedre on series of oil spills.	Sum of avoided costs per activity. Net avoided costs ~ €49 m (conservative estimate) as compared to total oil spill cost estimate: €450 m.

- Sassone and Weiher (1997) address ocean-atmosphere interaction models in the case study of the Tropical Ocean Global Atmosphere (TOGA) project. The objective of TOGA was to provide the modelling background for operational forecast related to the El Niño Southern Oscillation (ENSO) phenomenon, with a focus on US agriculture.
- Solow et al. (1998) analyse the value of improved ENSO forecast to US agriculture with a focus on cropping strategies.
- Kite-Powell and Colgan (2001) consider the observing system in the Gulf of Maine (GoMOOS) and the local activities which could use, and benefit from, available marine data: maritime transport, commercial fishing, recreational fishing and boating, search and rescue (SAR), pollution (oil spill) prevention.
- CEDRE[3] and Ifremer (2009) develop a case study in the framework of the EC-funded FP6 InterRisk project – a pilot system for interoperable GMES monitoring and forecasting services for risks in marine and coastal zones. The case study is the Erika oil spill in the Bay of Biscay (1999).

6.3.7 Conclusions

The above is a brief overview of the available methods to assess the performance of ENV RIs through upstream, downstream and feedback impacts. ENV RIs operate in a domain where commercial and non-commercial activities are in tight association: science and research; in-situ and satellite observations; requirements for commercial equipment; data supply to value-added services. Performance assessment methods are functions of these different segments.

1/ Each assessment method reviewed above is fit for a specific type of performance: business inquiries, KPIs, OSEs and ad-hoc CBAs.

Indicators focusing on the quality of observation data and ocean forecast are preferable to assess technical performance when there is no market. The remaining problem is to find correlations between these indicators and demand for products. Standard business statistics and ad-hoc business inquiries are preferable in cases of commercial interactions. CBAs can serve to assess the performance of the data generation chain from primary observations to value added services.

2/ Future work should focus on getting more experience on assessment methods. More data will be needed to identify correlations between the very different indicators and proxies used in the assessment methods. Experience gained from periodical update of evaluations (e.g. OSEs) would help to progress further in this direction.

[3] CEDRE: French state agency in charge of marine accidental pollution management.

6.4 References

Asmi, 2014. Environmental Research Infrastructure Strategy (ERIS) 2020". Final draft of ENVRI Report; Results presented at the ESFRI Environmental Strategy Working Group (ENV SWG) start-up meeting for the ESFRI 2030 roadmap, 22 May 2014, Paris, http://www.envri.eu/.

Bina, O., Mateus, S., Pereira, L., Caffa, A. (2017). The future imagined: Exploring fiction as a means of reflecting on today's Grand Societal Challenges and tomorrow's options. Futures 86: 166-184.

Boden, M., Cagnin, C., Carabias, V., Haegeman, K. & Könnölä, T., 2010. Facing the future: time for the EU to meet global challenges - EFP brief, European Foresight Platform (EFP). http://www.foresight-platform.eu/wp-content/uploads/2011/02/EFP-Brief-No.-179_Facing-the-future.pdf (13.06.2018).

Carval T., Bernard V., Bonnat A., Coatanoan C., Detoc J., Maronny J.-P., Petit de La Villeon L., 2015. *Coriolis data centre. Annual report 2015*. Ifremer/IMN/IDM/ISI/15-048, 39 pages. http://doi.org/10.13155/42402

Carval T., Coatanoan C., 2016. *Argo data management report 2016. Coriolis DAC and GDAC*. IMN/IDM/ISI-DTI/RAP-16-049. http://archimer.ifremer.fr/doc/00350/46128, 32 pages.

Cedre and Ifremer, 2009. *InterRisk project. Estimation of avoided consequences*. Internal note, WP 600, Task 5, Brussels: September 2009, 4 pages.

European Commission, 2007. GREEN PAPER The European Research Area: New Perspectives, Brussels, 4.4.2007, COM (2007) 161 final. http://ec.europa.eu/research/era/pdf/era_gp_final_en.pdf (13.06.2018)

European Commission, 2010. Communication from the Commission to the European Parliament, the Council, the European Economic and Social, Committee and the Committee of the Regions. Europe2020 Flagship Initiative Innovation Union, SEC (2010) 1161, Brussels. https://ec.europa.eu/research/innovation-union/pdf/innovation-union-communication_en.pdf (26.06.2018)

GODAE OceanView Science Team, 2014. *Strategic Plan 2015-2020*. Exeter, UK: GODAE OceanView Project Office, Dec., 54 pages.

Groupe interministériel sur la politique de diffusion des données d'observation de la Terre à partir de l'espace, 1995. *Politique de diffusion des données d'observation de la Terre à partir de l'espace*. Paris : ministère de l'Industrie, des Postes et Télécommunications et du Commerce extérieur, 78 pages.

Kite-Powell H.L., Colgan C.S., 2001. *The potential economic benefits of coastal ocean observing systems: The Gulf of Maine*. Washington: NOAA, ONR, Woods Hole OI, 13 pages.

McGrath, H.C., Horvath, V., Baruch, B., Gunashekar, S., Lu, H., Culbertson, S., Pankowska, P., Chataway, J. (2014). **The International Dimension of Research and Innovation Cooperation Addressing the Grand Challenges in the Global Context. Final Policy Brief.** RAND Europe. https://ec.europa.eu/research/innovation-union/pdf/expert-groups/eriab_final_policy_brief_international_R%26I_cooperation.pdf (13.06.2018)

Ministère de l'Education nationale, de l'Enseignement supérieur et de la Recherche, 2004. *Politique de diffusion des données d'observation de la Terre*. Paris : MENESR, 78 pages.

Mirtl et al., 2019. eLTER ESFRI proposal, publication in preparation.

Oke P.R., Larnicol G., Fujii Y., Smith G.C., Lea D.J., Guinehut S., Remy E., Alfonso Balmaseda M., Rykova T., Surcel-Colan D., Martin M.J., Sellar A.A., Mulet S., Turpin V., 2015a. "Assessing the impact of observations on ocean forecasts and reanalyses: Part 1, Global studies". *Journal of Operational Oceanography*, 8: sup1, s49-s62, DOI: 10.1080/1755876X.2015.1022067.

Oke P.R., Larnicol G., Jones E.M., Kourafalou V., Sperrevik A.K., Carse F., Tanajura C.A.S., Mourre B., Tonani M., Brassington G.B., Le Henaff M., Halliwell Jr. G.R., Atlas R., Moore A.M., Edwards C.A., Martin M.J., Sellar A.A., Alvarez A., De Mey P., Iskandarani M., 2015b. "Assessing the impact of observations on ocean forecasts and reanalyses: Part 2, Regional applications". *Journal of Operational Oceanography*, 8:sup1, s63-s79, DOI: 10.1080/1755876X.2015.1022080.

Reilly K., Cusack C., Fernández V., Buch E., Ott M., 2018. *Atlantic Ocean Observing Networks: cost and feasibility study*. AtlantOs project-633211, D1.4. Galway: Marine Institute, May, 84 pages.

Rémy E., Le Traon P.-Y., 2015. *WP3 Final synthesis report*. E-AIMS, D3.341. Brest: Ifremer, 9 pages.

Sassone P.G., Weiher R.F., 1997. "Cost benefit analysis of TOGA and the ENSO observing system". In: Operational oceanography: the challenge for European co-operation. Proceedings of the First International Conference on EuroGOOS. The Hague, 7–11 October 1996. Edited by J.H. Stel, H.W.A. Behrens, J.C. Borst, L.J. Droppert and J.P. van der Meulen. Elsevier Oceanography Series, 62: 36-50.

Solow A.R., Adams R.F., Bryant K.J., Legler D.M., O'Brien J.J., McCarl B.A., Nayda W., Weiher R., 1998. "The Value of improved ENSO prediction to US Agriculture". *Climatic Change*, 39:47-60.

Turpin V., Rémy E., Le Traon P.-Y., 2016. "How essential are Argo observations to constrain a global ocean data assimilation system?" *Ocean Science*, 12, 257-274, DOI: 10.5194/os-12-257-2016.

US National Research Council (2001). Grand Challenges in Environmental Sciences, Committee on Grand Challenges in Environmental Sciences, Oversight Commission for the Committee on Grand Challenges in Environmental Sciences, NATIONAL ACADEMY PRESS, Washington, D.C., ISBN: 0-309-51320-0, 106 pages, http://www.nap.edu/catalog/9975.html

Wan Z., Aydogdu A., Pinardi N., Korres G., Schultz-Stellenfleth J., Verlaan M., Sumihar J., Ponsar S., 2014. "OSE final report". JERICO project, D9.5. Brest: Ifremer, Dec., 49 pages.

Weiher R.F. ed., 1998. *Improving El Niño forecasting: the potential economic benefits*. Washington: U.S. Department of Commerce, NOAA, OPSP, 63 pages.