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GreenDIGIT

Greener Future Digital Research Infrastructures

Deliverable 3.1 RIs Landscape review, best practices analysis and identification of needs within the ESFRI RIs

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List of Abbreviations

Abbreviation	Description
DoA	Description of the Action (Annex of the Grant Agreement which contains the details of how the project will be carried out)
GPU	Graphics Processing Unit
HPC	High Performance Computing
HTC	High Throughput Computing
ICT	Information and Communication Technologies
LCA	Life Cycle Assessment
PUE	Power Usage Effectiveness
RIs	Research Infrastructures
SDGs	Sustainable Development Goals
WHR	Waste Heat Recovery
WPs	Work Packages

Executive Summary

This deliverable reports on the landscape analysis of digital Research Infrastructure (RI) practices and identified needs and gaps in existing practices, approaches, metrics, and tools in addressing environmental sustainability and impact lowering impact.

GreenDIGIT established a dedicated methodology to achieve insightful results. The work took place from March to November 2024 and involved three main stages: preparation, survey and interviews, and analysis of results with identification of key aspects. Key elements included desk research to define criteria, interactions with ESFRI DIGIT, careful development of the survey and interview materials with project partners, direct contact with RIs, and collaborative analysis with GreenDIGIT partners. From the outset, we defined the target survey participants as DIGIT RIs and RIs offering digital services.

The desk research phase for criteria identification enabled us to pinpoint key references, such as the European Code of Conduct for Data Centre Energy Management (EU DC CoC), European standards for data centre design and operation (EN50600), as well as international standards like ISO 50001, ISO 50002, ISO 14002, and ISO 30134, along with various technical publications and research on digital research infrastructures. We prioritized the criteria based on the EU DC CoC's prioritization framework, which we expanded slightly. This approach allowed us to establish the main sets of questions for the survey, which are about: energy consumption and energy efficiency, energy efficiency practices, impact of digital technologies (notably for digital RIs), renewable energy use, waste heat recovery, carbon emissions and greenhouse gas (GHG) management, waste management and recycling, and water usage. Additionally, the survey includes questions on other, lower-priority topics, asking participants whether they take actions in these areas and, if so, to describe those actions. We also checked the consistency of our survey with the Environmental considerations of the ESFRI Roadmap 2026.

Through the online survey and through interviews we managed to gather input about the landscape from: i) 3 DIGIT RIs that are on the ESFRI Roadmap: SLICES, EBRAINS, SoBigData, (ii) two European e-Infrastructure with the largest provider network: EGI and GÉANT, (iii) CERN: an EIRO with a large IT center, (iv) two thematic ESFRIs: CLARIN in language sciences and ELI-BEAMS in laser physics, and (v) two national/regional IT operators: Switch (CH) and University of Freiburg (DE). Most of the respondents are distributed RIs and their answers represent a larger number of stakeholders, so the total number of entities we reached with the survey is over 50. The survey data was complemented with a desk study of the HPC landscape through the TOP500 and GREEN500 lists.

The results of the survey highlight the diversity of situations regarding the environmental impact of digital research infrastructures. While most are fully aware of the challenges, and the results show progress, particularly in renewable energy use and energy efficiency, the majority remain at an early stage, lacking methodologies, policies, and resources to facilitate the transition. Thanks to the survey, not only was it acknowledged that there is still ample room for improvement (a non-trivial result), but it also became possible to measure its actual worth quantitatively. Existing approaches are often limited to energy consumption and rely on in-house methods that are difficult to integrate into more holistic carbon and waste management practices. However, a few have already implemented good practices, which can serve as a valuable resource for others. Sharing and benefiting from these best practices represents a clear call to collaborate to structure future efforts. Finally, it will be essential to discuss with ESFRI what steps should be taken to organize and promote best practices and potentially establish common policies.

The report makes the first attempt to collect solutions to fill the existing gaps and provide a list of good practices. A fully elaborated proposal will come in our next WP3 deliverable (D3.2) in August 2025, and in area-specific deliverables afterward.

While we continue working on these solutions, the project will also socialise and validate the landscape findings among an even broader set of stakeholders beyond those who could be engaged during the past 6 months. Besides electronic means the upcoming GreenDIGIT side event at the "International Conference at Research Infrastructures 2024" will provide immediate opportunities for such validation.

1 Introduction

This report presents the results of the survey conducted among digital Research Infrastructures (digital RIs) to give a landscape review, and the analysis of identified practices, needs, and gaps within these infrastructures as part of the GreenDIGIT project. This document is a crucial deliverable within the task T3.1 "Survey and landscape analysis of RI practices and needs," which primarily aims to gather detailed information from digital service providers within digital RIs, examining their practices, approaches, metrics, and tools used to promote environmental sustainability and reduce ecological impact.

The survey targets data from digital RIs with the objective of mapping and modelling the potential environmental impact of these infrastructures. Using various methodologies, including the survey, interviews, desk research, and analysis, this work provides a framework for understanding and optimising the environmental impacts of digital RIs.

The results of this study provide a baseline and context for other tasks and work packages (WPs) within GreenDIGIT, helping to identify opportunities for change, potential barriers, and best practices for broader adoption. The primary targets of this survey include DIGIT infrastructures and digital service providers within the Thematic Infrastructures of the ESFRI roadmap.

2 Survey methodology

2.1 Preparation

2.1.1 Definition of the target and overall strategy

We defined at the beginning of the preparation (the initial discussion took place at the GreenDIGIT kick-off meeting in March 2024, and detailed discussions started in April 2024):

- Survey objective: collect and analyse **RIs practices, needs and gaps, and opportunities-barriers-good practices** as defined in the GreenDIGIT Description of Action (DoA). It was key to define very early what to expect: the main questions to address and the level of detail.
- Target survey participants: **DIGIT RIs and RIs proposing digital services** as the main objective of GreenDIGIT, which is to increase the sustainability of digital RIs. We defined very early that we need to be focused and have direct contacts with the RIs. In this respect, we build on the knowledge and partnerships that the GreenDIGIT partners have with Thematic RIs.
- Methodology: based on a three-step process with **(i) preparation, (ii) survey and interviews, (iii) analysis of the results, and identification of key aspects**, as described in detail in this section. Our objective was to plan in advance.

2.1.2 Desk research for criteria

In order to define **the most relevant criteria** for the survey, we first conducted a strategic step of desk research to identify what had been done in the domain. The desk research for criteria is detailed in the following section 3.

2.1.3 Interaction with ESFRI DIGIT

We **informed the ESFRI DIGIT** Chair of our initiative as soon as we had a solid draft of the survey and a list of RIs that we planned to contact. We maintained this liaison in order to receive potential feedback and to synchronize for potential joint actions. We will come back to ESFRI with this deliverable to present our results to them and see how we can contribute to future actions of ESFRI in the domain of reducing the environmental impact of RIs.

2.1.4 Refinement of the target and list of RI contacts

After these first steps, we had **several meetings** with the GreenDIGIT partners and notably the ones in charge of the survey, in order to refine our target and list of RI contacts.

We also decided to **target the RIs for which we already have direct contacts** within the GreenDIGIT consortium so as to allow a better return rate. We asked all partners to list the RIs they are in contact with, and it confirmed that we would have enough RIs with 19 listed.

2.1.5 Choice of the survey platform

We considered several options for the survey platform to be used. After a first analysis, we pre-selected the 3 following services as suitable for our purpose: Google Docs, EUsurvey, LimeSurvey. We did a final selection based on the **criteria: (i) convenient use, (ii) allowing us to easily extract statistics, and (iii) confidentiality and privacy.** Based on this, we selected LimeSurvey (https://www.limesurvey.org/). It should be noted that regarding the third criterion of confidentiality and privacy, LimeSurvey was recommended by Sorbonne University's IT security department.

2.2 Survey and interviews

2.2.1 Elaboration of the survey with all partners

This action was a **long step as it needed a lot of interactions and iterations** between the partners: we started a first draft in early April 2024 and we reached the final version in mid-June 2024, so it took a bit more than 2 months.

Based on the definition of our target and on the results of the desk research criteria, we initiated the first version in early April. Then, we had a lot of meetings and interactions to reach the final version. During this period we used a Google Docs document as it was easier to interact through it. A crucial part during the end of this process was to **prioritize the criteria and reduce the length** of the survey to be manageable by the RIs contributors.

2.2.2 Distribution of the survey

The **final version of the survey was sent in mid-June 2024** to the GreenDIGIT partners in charge of the relations with the targeted RIs, and they directly contacted them and filled an internal monitoring table to track the progress. The **deadline given to the RIs was the end of August 2024** to provide them with enough time to have internal discussions.

This distribution allowed us to **meet on time the milestone MS2 "Surveys distributed to identified DIGIT service providers"** of the GreenDIGIT project. It was achieved on 21 August with the **survey distributed to 19 RIs**.

Some of the RIs, for example EGI, cascaded the survey within their stakeholder groups and acted as a proxy to integrate Individual responses into a single submission to the LimeSurvey form. While such single submissions capture the overall state of the RI as an integrated system, also respect and highlight the levels of diversity that existing among the RI nodes with respect to environmental impact monitoring and lowering.

2.2.3 Interviews

We proposed to RIs to set up interview meetings and/or to answer their questions to facilitate their survey completion.

Several questions were directly answered by the partners in charge of contacting the RIs, and by the partners in charge of the survey.

Finally, **one RI, CLARIN, opted for an interview meeting instead of** completing the survey. We prepared for this interview a set of dedicated questions that would be more pertinent for a video conference discussion, but that will still correspond to the survey.

2.3 Analysis and identification of key aspects

2.3.1 Analysis

The first analysis started as soon as we received a few survey responses in August and September 2024, to understand the trend and the potential key aspects and to orient the questions for the interviews.

We **then refined the analysis** by extracting statistics from LimeSurvey and comparing them with the criteria identified through desk research in October and November. And we discussed it within GreenDIGIT.

2.3.2 Identification of key aspects and preparation of the deliverable

After analysing the statistics and results, a crucial step was to **identify key insights** from our survey and to prepare this deliverable. **Each partner involved in the process was responsible for leading specific areas** in collaboration with the other partners. We then created **several versions to refine** it further.

2.3.3 Feedback from RIs about the deliverable

A final step will be gathering feedback from the RIs. We will **first deliver the current version to the EC and, in parallel, ask the RIs to review it before making it public** in a second step. This process is essential not only for improving the quality of the deliverable but also for ensuring compliance with any confidentiality requirements from the RIs.

3 Desk research for criteria

3.1 Overall strategy for desk research for criteria

The strategy was to ask partners to identify key references to establish our list of criteria, and then to review the list of references provided and to select the main references to be used.

3.2 Main references found to establish the list of criteria

We selected the following main references:

Main references
European Code of Conduct for Data centre Energy management (EU DC CoC) This is the key and practical document produced annually by the European Commission (EC) and Joint Research Centre (JRC). We refer to the publication of 2024: ***European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)***, Publications Office of the European Union, Luxembourg, 2024, JRC136475 https://data.europa.eu/doi/10.2760/093662 ***European Commission, Joint Research Centre, Acton, M., Bertoldi, P. and Booth, J., 2024 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency***, European Commission, Ispra, 2024, JRC136986. https://e3p.jrc.ec.europa.eu/sites/default/files/documents/publications/jrc136986_2024_best_practice_guidelines.pdf **Commission Delegated Regulation (EU) 2024/1364 of 14 March 2024 on the first phase of the establishment of a common Union rating scheme for data centres**, 14 March 2024 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1364&qid=1723470355995
European developed standards on data centres design and operation EN 50600
International standards: **ISO 50001 Energy management systems** **ISO 50002 Energy audits** **ISO 14002 Environmental management systems - Guidelines for using ISO 14001 to address environmental aspects and conditions within an environmental topic area** **ISO 30134 Information technology - Data centres key performance indicators**
Technical publications and research on digital research infrastructure
Energy Efficiency: An Overview - Future Networks. (2019, May 8). GSMA. Retrieved April 3, 2024, from: https://www.gsma.com/solutions-and-impact/technologies/networks/gsma_resources/energy-efficiency-an-overview/
Indicators for Environmental Sustainability. Yan Dong, Michael Z. Hauschild. Procedia CIRP 61. (2017): 697-702. DOI:10.1016/j.procir.2016.11.173

	How to Calculate and Measure Greenhouse Gas Emissions. (2023, July 10). Ecometrica. Retrieved April 3, 2024, from https://ecometrica.com/knowledge-bank/guides/how-to-calculate-measure-ghg-emissions-guide/
	ATIS White Paper Green G: The Path Toward Sustainable 6G [online] https://nextgalliance.org/white_papers/green-g-the-path-towards-sustainable-6g/
	***ARCEP - Enquête annuelle "Pour un numérique soutenable" - édition 2024 (données 2022)* - In French only - Annual survey "For a sustainable digital world" – 2024 edition (2022 data)** [online] https://www.arcep.fr/u/c8tz-aa4a
	The Shift Project - Digital https://theshiftproject.org/en/category/thematic/digital/

We also took into account in our preparation of the survey the following reports:

- ***ESFRI Report on Energy and Supply Challenges of Research Infrastructures***, Published July on 5 July 2023 (https://zenodo.org/records/8123921)
- ***Assessment Framework for Data Centres in the Context of Activity 8.1 in the Taxonomy Climate***, Bertoldi P. *Delegated Act , European Commission, Ispra, 2023, JRC131733* **https://e3p.jrc.ec.europa.eu/publications/assessment-framework-data-centres-context-activity-81-taxonomy-climate-delegated-act**
- **D7.4 Green Computing progress and improvements within EGI-ACE**, report produced by EGI-ACE Task 7.2 and the EGI Green Computing Task force, published on 16/02/2023 (https://zenodo.org/records/7670205).

The detailed references used for the survey were made available to the participants to the survey, they are provided in the attached Annex B.

3.3 Prioritisation of criteria

After analyzing the different references (see Annex B "GreenDIGIT Survey References", which was made available as an annex document of the survey), we decided to **base the prioritisation according to the publication of the JRC "EU DC CoC"** in the report "Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)".

The table below ranks the indicators from most to least prioritized (must, should, nice to have) using color-coding (red, yellow, green).

Indicator	Classification
Energy consumption	Must Have
Energy efficiency	Must Have
Use of renewable energy	Must Have
Waste heat recovery	Must Have
Carbon Emissions and Greenhouse Gas	Must Have
Waste Sorting and Recycling	Must Have

Waste Reduction at Source	Should Have
Recycling	Should Have
Raw Material	Should Have
Water Usage	Should Have
Waste heat recovery	Nice To Have
Composting	Nice To Have
Energy from Waste	Nice To Have
Responsible Disposal	Nice To Have
Land Use	Nice To Have
Ecotoxicity	Nice To Have
Human Toxicity	Nice To Have
Eutrophication	Nice To Have

3.4 Checking Consistency with the Environmental considerations of ESFRI Roadmap 2026

In the framework of the preparation of the updated version of its Roadmap, to be completed in 2026, ESFRI has included a new dimension in the scientific case, called "Environmental considerations". This new dimension targets to evaluate the planning and deployment of an environmental strategy and the adoption of plans regarding environmental sustainability. It includes the addition of a new set of Minimal Key Requirements for this purpose.

We have thus checked that our list of criteria was consistent with the "Checklist for dimension Environmental considerations"[1] (see Annex C) defined by ESFRI to assist the formulation of answers to the dimension "Environmental considerations". As described in this checklist, "it provides the substantive environmental 'headline' issues for which ESFRI project proposals are invited to examine whether they are relevant (hence to be addressed in an environmental strategy) or not, as the case may be." The elements are listed in relation to their appearance in the series of environmental (draft) European Sustainability Reporting Standards and their so-called 'disclosure requirements'.

Our conclusions are:

- The scopes of the two initiatives share the same objectives that the RIs are better aware of their environmental impact and plan and deploy actions to reduce their impact.
- But the scopes are not exactly similar: the environmental considerations have a larger scope (as for example it takes into account the resilience to climate change, or the assets at material risk addressed by the climate change adaptation actions).
- And the scope of the domains of the considered RIs is of course different: we target first digital RIs where the Environmental considerations target all RIs (so with a larger scope of potential issues such as related to indigenous knowledge, agriculture practices, or sustainable ocean/seas).

[1] https://www.esfri.eu/sites/default/files/ENVIRONMENTAL%20CONSIDERATIONS%20Checklist.pdf

- However, **we confirm the overall consistency of our initiative with the Environmental considerations of the ESFRI Roadmap 2026**, as we match the same key indicators such as energy consumption and efficiency, GHG emissions, waste and pollution.
- For future work in GreenDIGIT, we will have to continue to make reference to the ESFRI Environmental considerations, and to work on how to better join our work and forces on this key topic.

3.5 Final list of criteria

We decided to **take all the "must have" criteria, and to add the "should have" criteria about water usage**, as some GreenDIGIT partners identified it as another potential key topic. So, this is the basis of the main set of questions for the survey, with detailed questions for each topic.

We also **added a section about "other topics"** to cover all the other criteria where survey participants can say if they take actions for each topic and how. This is, of course, a shorter and limited scope compared to the main sections, but it allows us to have an overall picture with no blind spot.

3.6 Main sets of questions of the survey

Following the final list of criteria, we prepared the detailed survey with the following main sets of questions:

- **Contact information**
- **Preliminary questions about your Research Infrastructure**
- **General questions about energy consumption and energy efficiency**
- **Energy efficiency**
- **Impact of digital technologies, notably for digital RIs**
- **Renewable energy use**
- **Waste heat recovery**
- **Carbon emissions and greenhouse gas (GHG) management**
- **Waste management and recycling**
- **Water usage**
- **Regarding the following topics: do you take actions? If yes, please explain what actions?**
- **Concluding questions**
- **Final question**

The full survey with the detailed questions is attached in the Annex A.

4 Overview of results of the analysis of RIs practices

This chapter contains a thorough representation and analysis of the results (responses) retrieved after the GreenDIGIT's survey distribution. The **best practices, approaches, metrics, and tools regarding environmental sustainability and impact reduction** are some of the points that are analysed in the context of this section. It is worth noting that the survey was developed based on existing European and International Regulation, Best Practices and ISO Standards.

Several questions were included in the survey, which cover the subjects of addressing environmental sustainability and lowering impact within each RI by including:

- Energy Efficiency
- Impact of Digital Technologies, Notably for Digital Research Infrastructures (RIs)
- Renewable Energy Use
- Waste Heat Recovery
- Carbon Emissions and Greenhouse Gas (GHG)

The collected data can be used to define a generic model of RI-environment interaction and will also serve as a basis for other tasks and work packages of GreenDIGIT. In such a way, it is foreseen that GreenDIGIT will create new technologies and solutions for reducing the environmental and climate footprint of RIs.

4.1 Preliminary and General RI Information

Before delving into the details, it is essential to analyse the general information of the RIs participated in the survey, though multiple preliminary questions. This step is crucial for laying the groundwork for the detailed analysis given in the next subsection, and, in parallel, it helps to minimizes misunderstandings and potential errors throughout the result extraction.

4.1.1 Type/size of the participated RIs

Initially, there were 10 respondents (referred to as RIs from now on) that participated in the survey and provided valuable input. The respondents were the following (in alphabetical order):

The 4 GreenDIGIT RIs:

- **EBRAINS**: EBRAINS provides a digital research infrastructure that accelerates collaborative brain research between leading organizations and researchers across the fields of neuroscience, brain health, and brain-related technologies.
- **EGI**: A federated e-infrastructure providing cloud, HTC, HPC and data services, as well as higher level platforms for the support of compute-intensive science. The EGI response was compiled from individual responses received from 15 EGI members[2] who voluntarily participated in this exercise and who serve over 20 thematic RIs in their computational needs.
- **SLICES**: Distributed RI with 15 national nodes, SLICES is in the Preparation Phase (started a pre-operation phase on 8th Nov. 2024). SLICES is a flexible platform designed to support large-scale, experimental research focused on networking protocols, radio technologies, services, data

[2] The EGI data centres that participated in the survey are located in the following countries: CZ, ES, FR, GR, HR, HU, IT, LT, NL RO, SK, UK, TR

collection, parallel and distributed computing, and, in particular, cloud and edge-based computing architectures and services.

- **SoBigData**: SoBigData RI is a distributed, pan-European, multidisciplinary research infrastructure involving 14 national nodes which is included in the ESFRI Roadmap 2021 (currently in its Preparation Phase). The RI focuses on leveraging social mining and big data to analyse societal complexity and address challenges such as misinformation, disinformation, sustainable mobility, personalized health and the impact of AI.

6 external RIs:

- **CERN**: the European Organization for Nuclear Research, is one of the world's largest centres for scientific research and it has a significant IT infrastructure to support data analysis related to its unique range of particle accelerators. CERN is also a member of EGI.
- **CLARIN**: A digital infrastructure offering data, tools and services to support research based on language resources. The operations, services and centres of the CLARIN infrastructure are provided and funded by the national consortia in the countries that have joined CLARIN ERIC, as well as by associated centres.
- **ELI-BEAMS**: a leading laser research centre in the Central Bohemian region of the Czech Republic, and part of The Extreme Light Infrastructure ERIC. ELI Beamlines has developed and operates four leading-edge high-power femtosecond lasers and related IT infrastructure for storage and data analysis.
- **GÉANT**: GÉANT delivers the pan-European GÉANT network for scientific excellence, research, education and innovation. Through its integrated catalogue of connectivity, collaboration and identity services, GÉANT provides users with access to computing, analysis, storage, applications and other resources. All survey respondents rely on the GÉANT network.
- **Switch Cloud**: OpenStack-based computing cloud provided by Switch, a private foundation established by the Swiss Confederation and eight university cantons in 1987. The mission of the Switch foundation is to enable and continuously expand a secure and networked research and education infrastructure in Switzerland. Switch is a GÉANT member.
- **University of Freiburg Compute Center**: The Compute Centre of one of Europe's strongest research universities, supporting both individual disciplines and in collaborative research. The compute infrastructure is part of larger structures for HPC and cloud operation, and contributes to de.NBI (German Network of Bioinformatics Infrastructure) and to EGI.

Figure 1 depicts the different RI types which are given in the available responses.

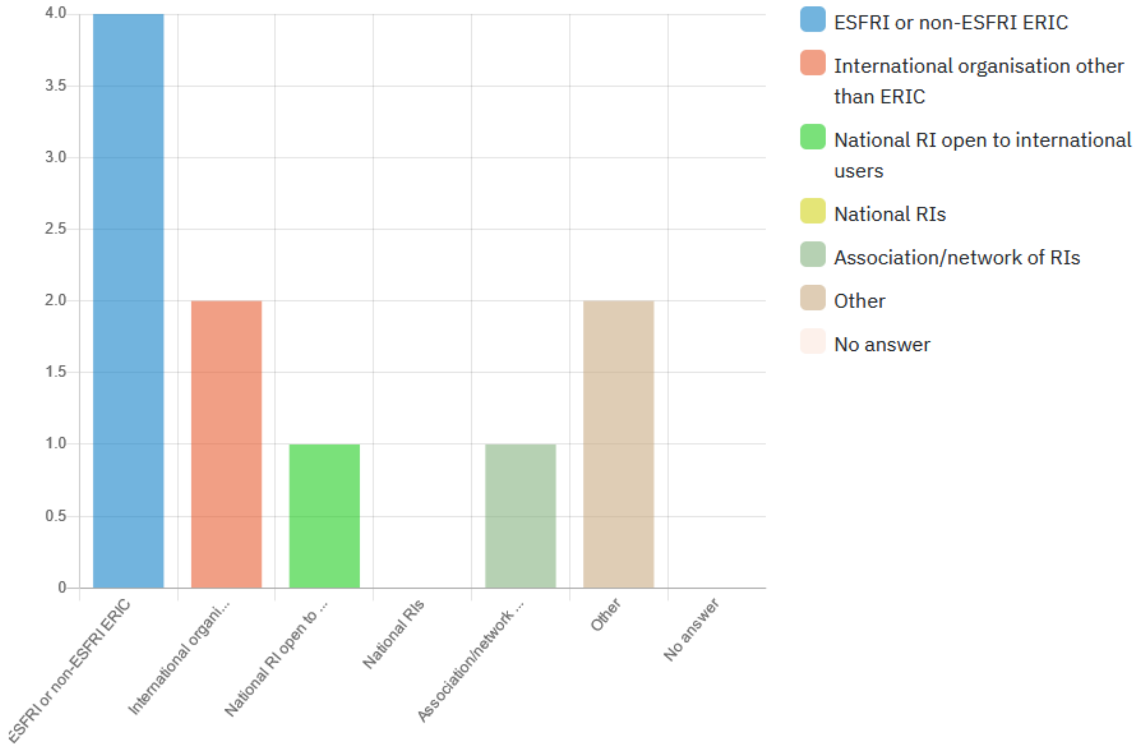

Figure 1 Type of research infrastructure

More specifically, there were 4 responses from "ESFRI or non ESFRI ERIC", 2 from international organisations other than ERIC, 1 from "National RI open to international users", 1 from "Association/network of RIs" and 2 responses that characterized their type of RI as "Other", including types as "Local and Regional RI".

Furthermore, Figure 2 presents the primary resources that each RI mainly offers access. It is worth noting that at this question, each representative was able to select more than one option.

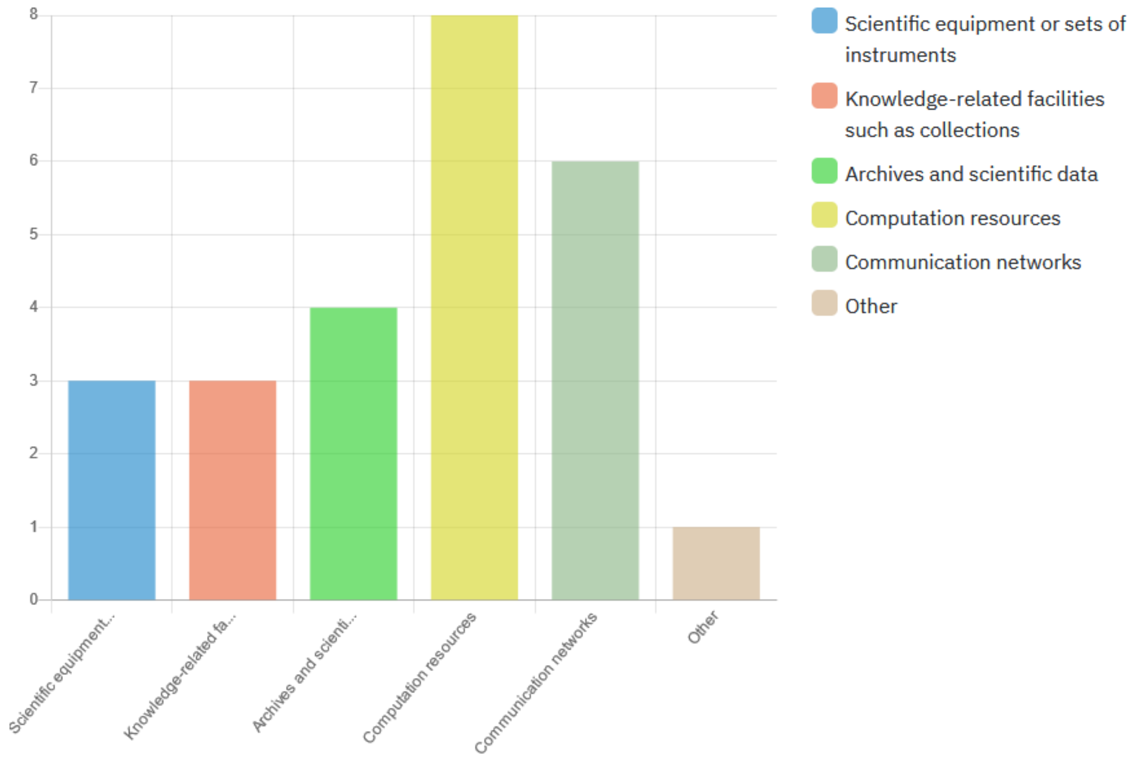

Figure 2 Primary resources offered from RI

Thus, from the graph, it can be observed that the vast majority (80%) of the participants offer "Computation resources" as a primary resource. Following that, 6 of them (60%) offer "Networking / Communication resources" and 4 (40%) archives and scientific data. Moreover, 30% of the participating RIs offer "Scientific equipment / instruments" and "Knowledge-related collections" At this question each RI was able to select more than one option as primary resources.

The Central Hubs / Headquarters for all the RIs that participated in the survey are in the European Union. Moreover, the available survey responses include 8 RIs which are distributed (80%) and only two (20%) are defined as single-sited RI.

There is a variation in the number of the users served per year for each participating RI , which ranges from 60 users to 50 million users. Further details about their size can be found in Table 1[3].

Table 1: RI size indicators

Data Centers (min / max)	Servers (min / max)	Storage capacity (min / max)
2 / 200+	39 / 10000+	100TB / X PB

4.1.2 Environmental sustainability results (general)

This subsection focuses on the tools and techniques that are already applied in the RIs for addressing environmental sustainability and lowering impact. Initially, it is relevant to first identify if the RIs track its total energy consumption (electricity, gas, water, etc.).

[3] The table contains the answers in which the values given were >0.

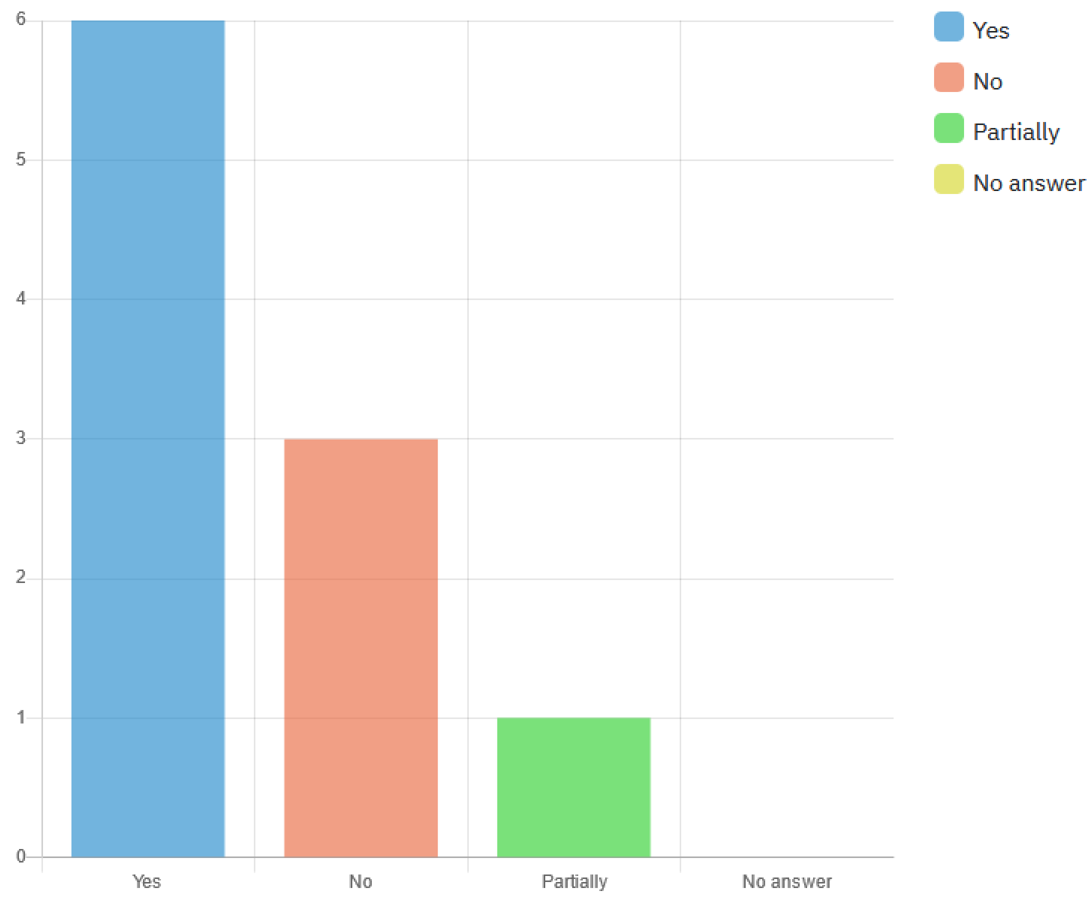

Figure 3 Energy consumption tracking

Figure 3 represents the percentage of RIs that take into consideration partially or extensively energy consumption tracking (70%) and compared to those that do not at all (30%). However, it was not declared from the responses on how energy consumption is monitored and measured (e.g. with smart meters, building management systems etc). Moreover, 71.42% (5 of 7) of the RIs consider the energy consumption tracking (those who answered "Yes or partially" in Figure 3), also have an estimation for the current energy consumption per year, which is averaged on the collected results to 2.06 million KWh. This average value corresponds to the RIs (2 out of 7) which stated exact numbers for their energy consumption. Moreover, these 2 energy consumption numbers were pretty close to each other, with a standard deviation of 131.020 and a relative standard deviation of ~6.3%.

Regardless of each RI's actions on energy consumption tracking, Figure 4 highlights the primary factors that are noted to contribute more to RI energy consumption. There, it can be observed that "Data centers" is the dominant answer (80%), followed by "Network" (50%). It is noted that these results are strongly consistent with those given in Figure 2. Except from those depicted, GPU, Scientific instruments and maintaining an appropriate environment for scientific experiments are also considered to act as primary factors for the energy consumption of the RIs.

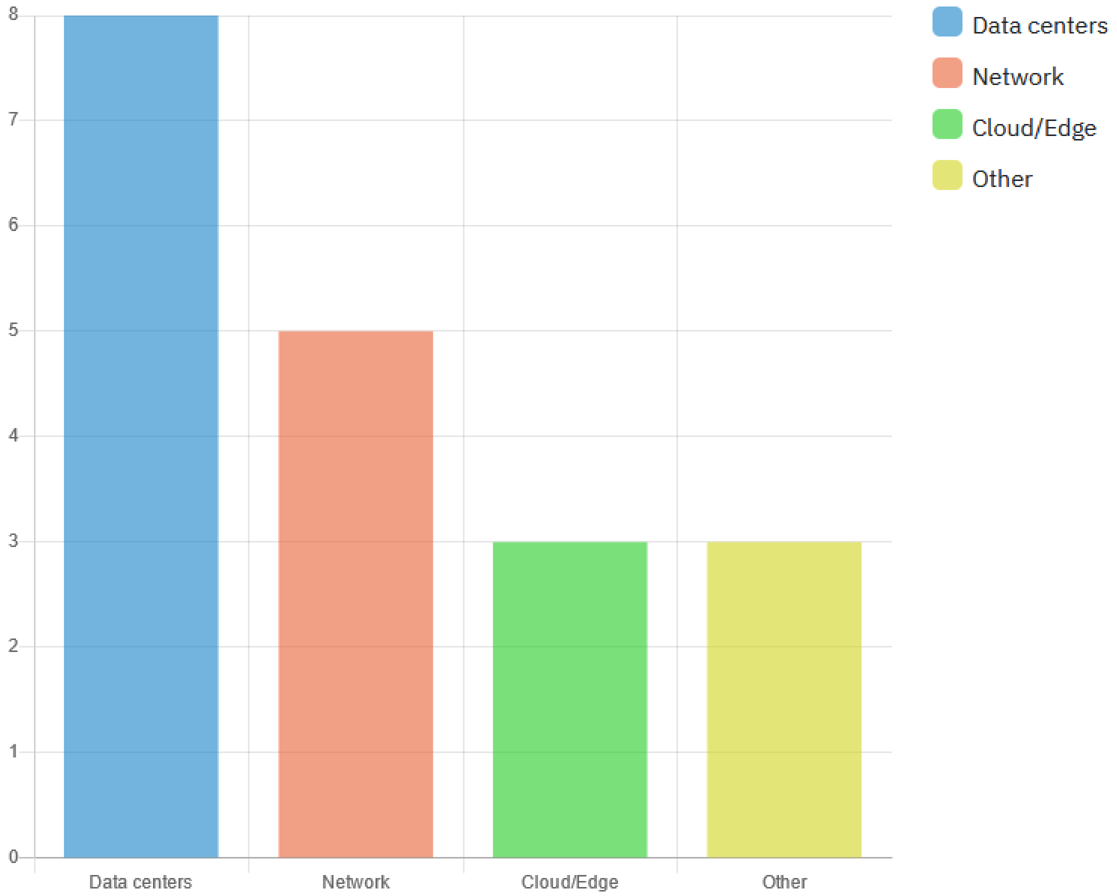

Figure 4 Energy consumption primary factors

The ***initiatives taken to decrease the energy consumption*** from the responded RIs are summarised below:

- **Infrastructure / Hardware**
  - Building new computer centers with better efficiency (Avoiding waste by giving away older equipment to developing countries for reuse)
  - Plan to equip the infrastructure with energy consumption monitoring capabilities. Research experimentation tools will allow energy estimation when designing the experiment
  - Equipment selection and renewal based on energy efficiency/consumption.
  - Optimization of the lifetime of equipment with respect to the overall carbon footprint.
  - Enterprise hardware, Green Datacenters ISO certified
  - Switching off unused nodes
  - Limiting the maximum consumption
- **Workflow**
  - Monitoring the power consumption of workloads and profiling workloads for improved efficiency
  - Working with experiments and theory on improvements of the efficiency of the workloads
  - Planned: Increased training for improved code and workflow efficiency
- **Generic**

- Innovation programs (Training and knowledge sharing) to provide researchers with insight on the energy consumption of their research to raise awareness within their communities
- Photovoltaic unit and cogeneration unit installed on-site
- Replacement of facility technology management system
- Replacement of lighting sources to more sustainable options - LED
- Replacement / Improvements of central cooling systems
- Data centre physical reorganization, including hot/cold aisles and water cooling (in progress)
- Cleaner energy providers, designed redundancy/wind down
- Certain aspects being cloud managed
- Energy sensitive sourcing

Those efforts already made to reduce consumption consider some energy efficiency metrics. More specifically, the amount of energy consumed (KW - KWh) from individual servers/racks, and/or for the whole facility is the most common answer on the surveys completed. In some cases, the RIs perform annual comparisons for the energy consumed to track their progress over time. Finally, 40% of the RIs do not apply metrics for energy efficiency, or they are now researching / studying this subject as the RI is still in pre-operation phase. Correspondingly, 40% of the responding RIs, do not consider specific KPIs for energy consumption and efficiency right now. The remaining either apply generalized KPIs like overall energy consumption (aggregated with other services), or more specific ones like:

- Establish a real-time power consumption tracker of network energy usage.
- Emission sustainability scoring criteria for new tenders.
- Criteria of equipment material, i.e., circular economy efforts.
- Server auditing – identify unused/underutilized servers and shutdown/consolidate periodically.
- Periodic removal of old equipment.
- The amount of energy consumed in relation to the service provided (number of cores/performances, storage space)

4.2 Energy Efficiency

In this subsection, the answers to several specific questions on energy efficiency are given and thoroughly analysed. Initially, the percentage of the RIs that apply a formal energy efficiency policy is depicted in Figure 5.

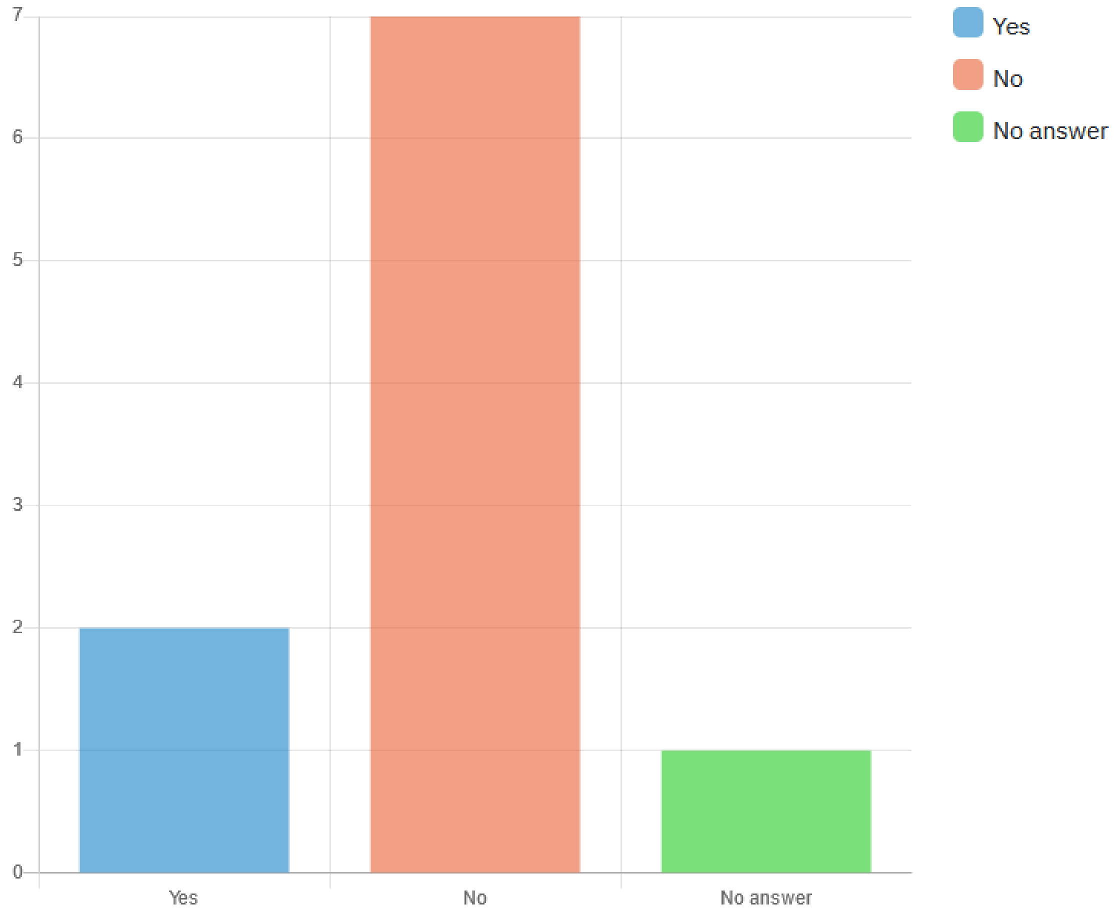

Figure 5 Formal energy efficiency policies

It can be observed that the majority of the RIs in the collected statistic sample do not follow a formal energy efficiency policy (80%). However, things are different the RI conducted energy audits to identify opportunities for improving energy efficiency. Moreover, it is worth noting that the Ris implementing energy consumption tracking (Figure 3), are exactly the same with the RIs conducted energy audits to identify opportunities for improving energy efficiency.

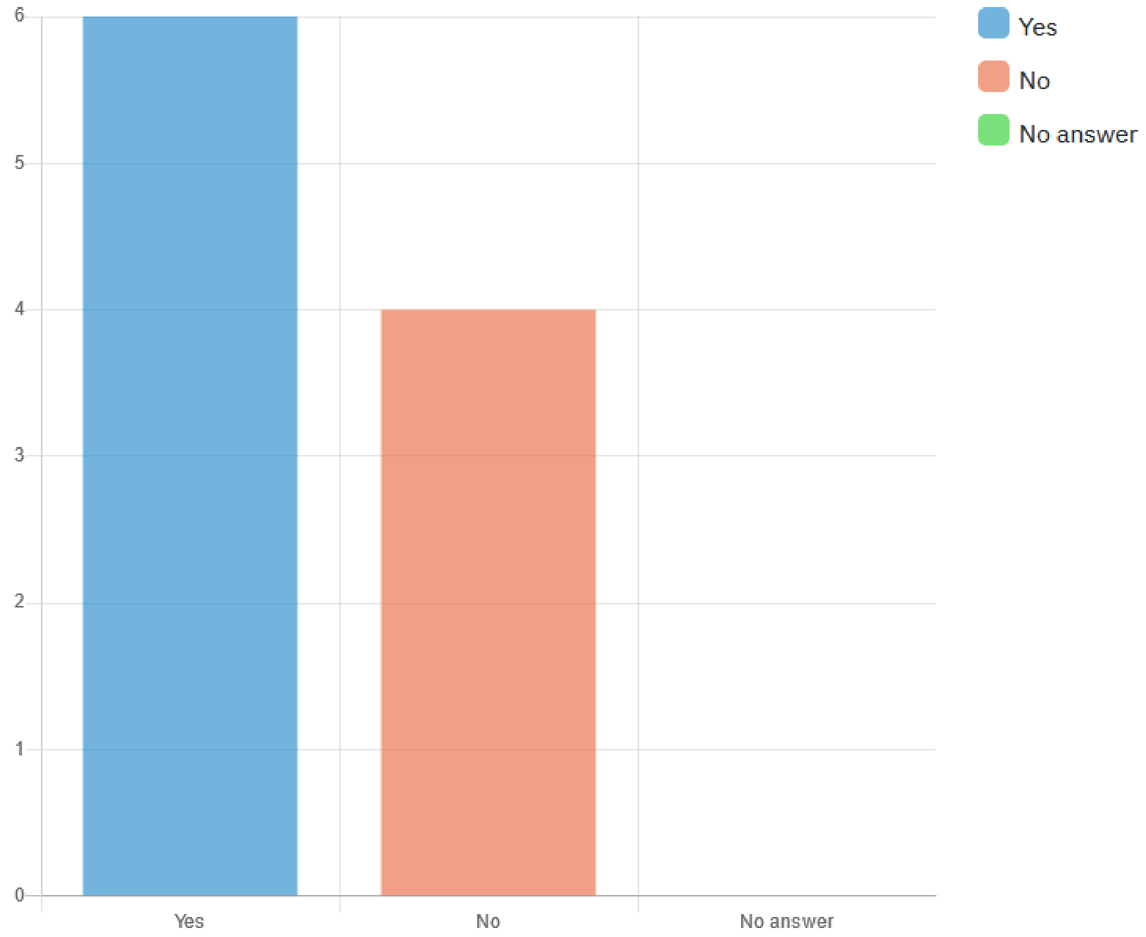

Figure 6 Audits for energy efficiency improvements

Here, it is noted that most of the RIs (60%) conducted audits which target potential energy efficiency opportunities. Furthermore, the amount of RIs that already applied energy efficiency measure(s) is the same in the previous question. More specifically, 6 out of 10 RIs claimed at least one of the following measures:

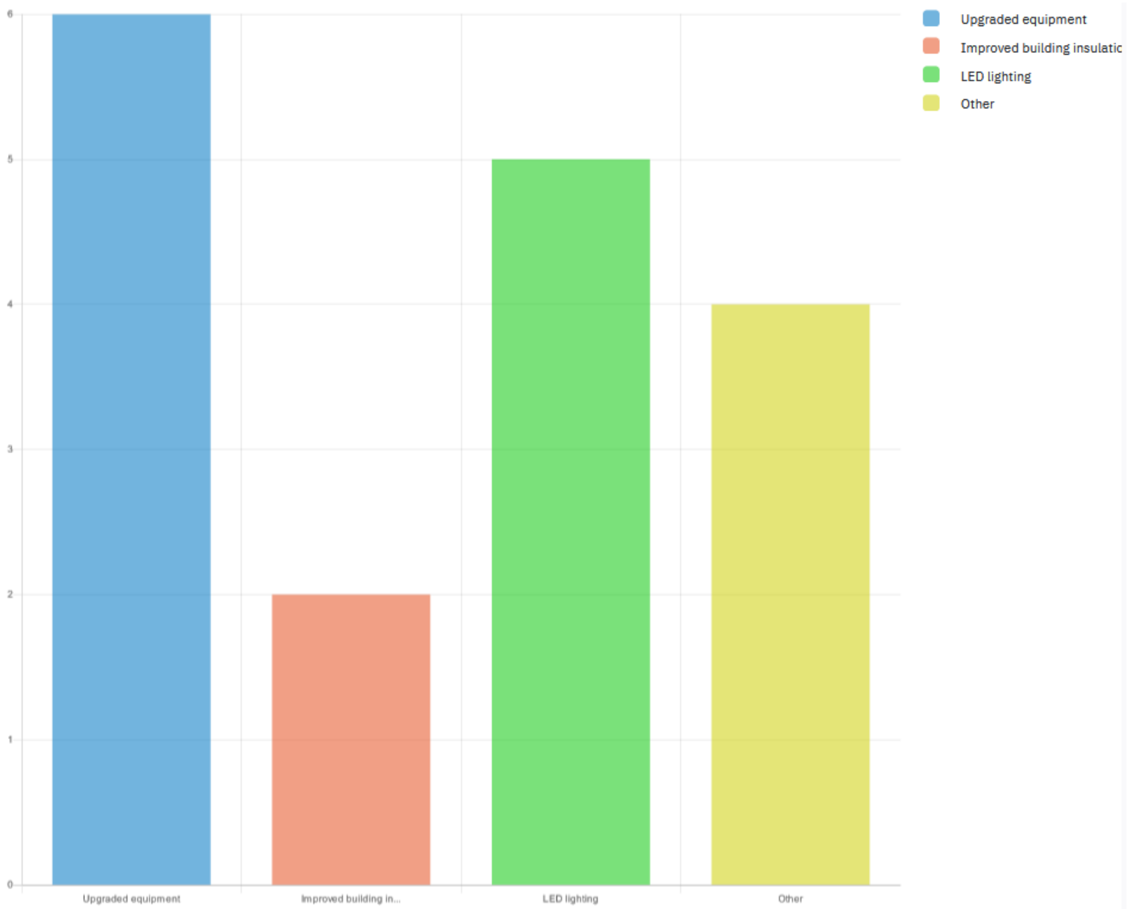

Figure 7 Energy efficiency measures

Here, the response "Other" includes the "***initiatives taken to decrease the energy consumption*** " as mentioned above in Section 4.1.2, and some additional waste heat usage. Besides the formal policies, the audits and the measures are taken regarding energy efficiency, 4 out of 10 (40%) of the RIs have programs to educate and encourage the personnel on energy saving practices. These education programs / encouragements can be summarized as follows:

- Inform personnel of similar research projects/initiatives which regard energy efficiency.
- Reducing personnel travel (especially airplanes), bicycle use and encourage commuting not using cars.
- Campaigns to encourage personnel to be careful with energy consumption (e.g. switch off lights, computer screens etc).
- Provide software recommendations for efficiency.

Next, there was an evaluation of how each RI's representative would rate their energy efficiency on a scale of 1% - 100% (1=inefficient - 100=extremely efficient). There were various answers ranging from 5% to 90% with a standard deviation of 29.25 and an average value of 58.33%. Furthermore, regardless of the energy efficiency policies, audits or measures, 60% of the RIs stated that they chose the technical architecture for the services provided, based on the environmental impact.

The energy efficiency short-term and long-term goals can be indicatively summarized among all questionaries as follows:

- Improve energy efficiency

  - Evaluate the energy impact (implement more precise measuring and establish related KPIs)
  - Monitor and reduce energy consumption
  - Reduce CO2 emissions
  - Automatic power on/off physical nodes
- Reduce energy consumption / reaching NetZero[4] within a specific time.
  - Replacement of old hardware (like lighting by LED)
  - Select new hardware based on energy efficiency
- Recovery of waste heat from the operations.
- Displacement of specific services (or servers) to cloud.
- Policy addressing on energy consumption and carbon footprint (By providing measurement capabilities).
- Raise awareness of the shared responsibility of RI operators/centers and users / researchers (By also providing corresponding tools).

These goals are either included in the general directions of each RI and ongoing or planned (research) projects, which also include GreenDIGIT among others.

4.3 Impact of Digital Technologies on RIs Energy Efficiency

This subsection describes the survey's results related to Impact of digital technologies, notably for digital RIs. Initially, 30% of the responders stated that they had already implemented some digital technologies specifically aimed at improving energy efficiency within their operations. More specifically:

- The purchase of up-to-date technology / renewal of old equipment.
- The selection of the appropriate equipment type
  - CPU (some consider Thermal Design Power and price per core)
  - GPU models
  - SSD / flash memory (some consider TB/KW ratio)

All the RIs that already implemented these kinds of digital technologies, note neutral or improved energy efficiency and impact on the quality of their offered services. In parallel, these technologies lead to either reduced cost or cost-neutral influence on RI's operating services.

However, the above factors do not necessarily mean that the RIs implement specific workflow optimization strategies to minimize energy consumption. Some actions that are included in the scientific workflow contain:

- The creation of organizational Greening committees
- Contact with major users of the RI to ensure better use of the infrastructure

Furthermore, Figure 8 showcases that a relatively large number (40%) outsource on-demand computation tasks to cloud, for optimizing energy usage within their RI. Furthermore, the quality of RI services is noted to be improved / neutral, after utilizing digital technologies for improving energy consumption. The use of these technologies leads to reduced or neutral costs of operating services, as

[4] https://www.un.org/en/climatechange/net-zero-coalition

noted. However, it is worth noting that improved energy efficiency was reported for 3 out of the 10 Ris that responded to the survey.

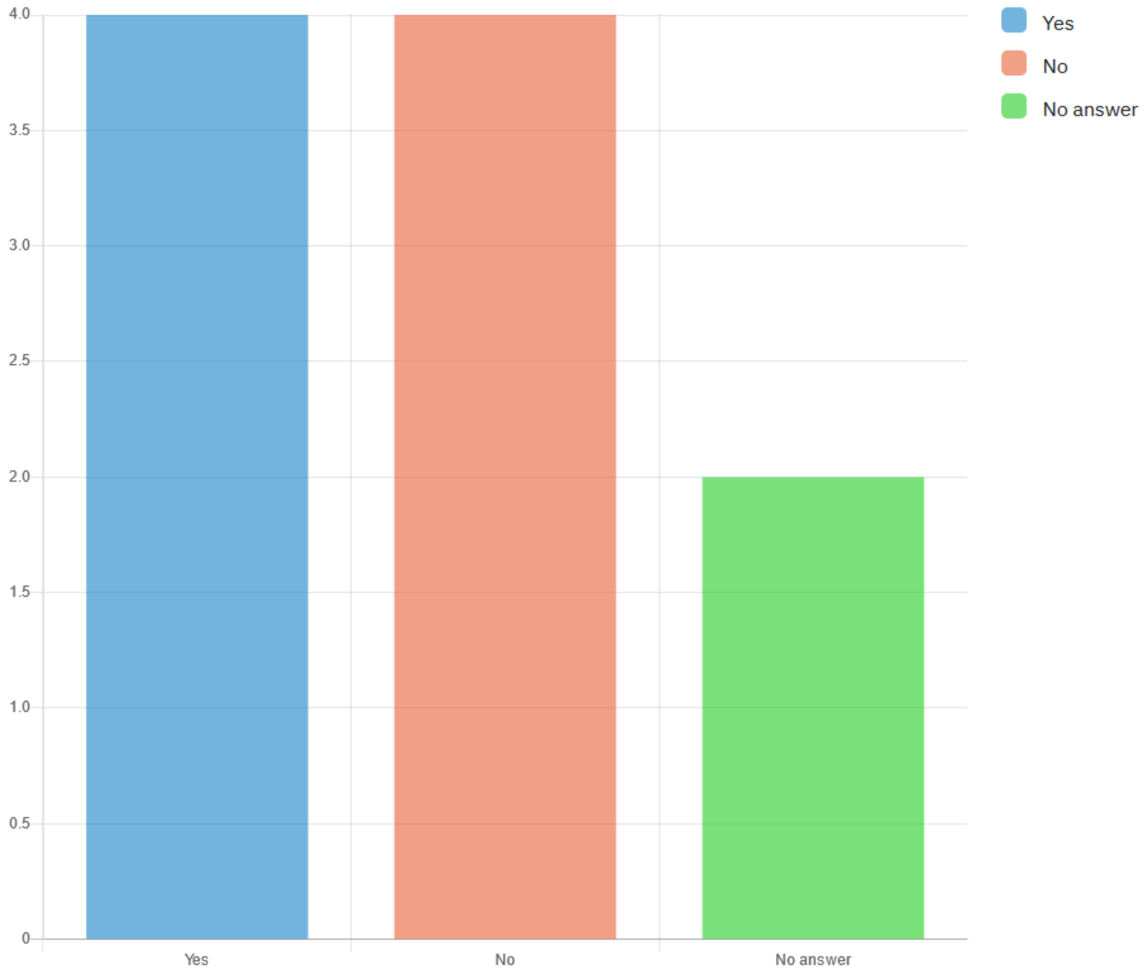

Figure 8 Cloud computation tasks outsourcing

4.4 Renewable Energy Use

Regarding the utilization of renewable energy sources (e.g., solar panels, wind turbines, green energy suppliers), half of the participated RIs (50%) are already using (and able to measure) these kinds of technologies, to improve their energy efficiency, while 80% of them are also exploring additional opportunities to increase the use of renewable energy. For those RIs, which can measure the percentage of total energy consumption that comes from renewable sources, the results show answers ranging from 2% - 100%. Finally, the responses also showcased that the rest of the RIs that do not currently utilize renewable energy sources plan to implement this in the future.

4.5 Waste Heat Recovery

Following, the vast majority of the RIs (70%) are aware of the significant amount of waste heat generated from their operations. More specifically, these operations can indicatively include waste heat from cooling systems, high-performance computing and others. However, this is not the case if there are existing solutions that capture this wasted heat and reuse it efficiently. Specifically, 50% of the participants note that their RI does not consider any waste heat reuse at this moment, or this process is unknown to them. Moreover, 20% state that there is an initial evaluation and early application among planning through projects or similar initiatives. Finally, only 30% follow some specific structured ways to capture and reuse waste heat. Finally, the trend on if the RIs actively investigate the implementation of waste heat recovery systems is depicted in Figure 9.

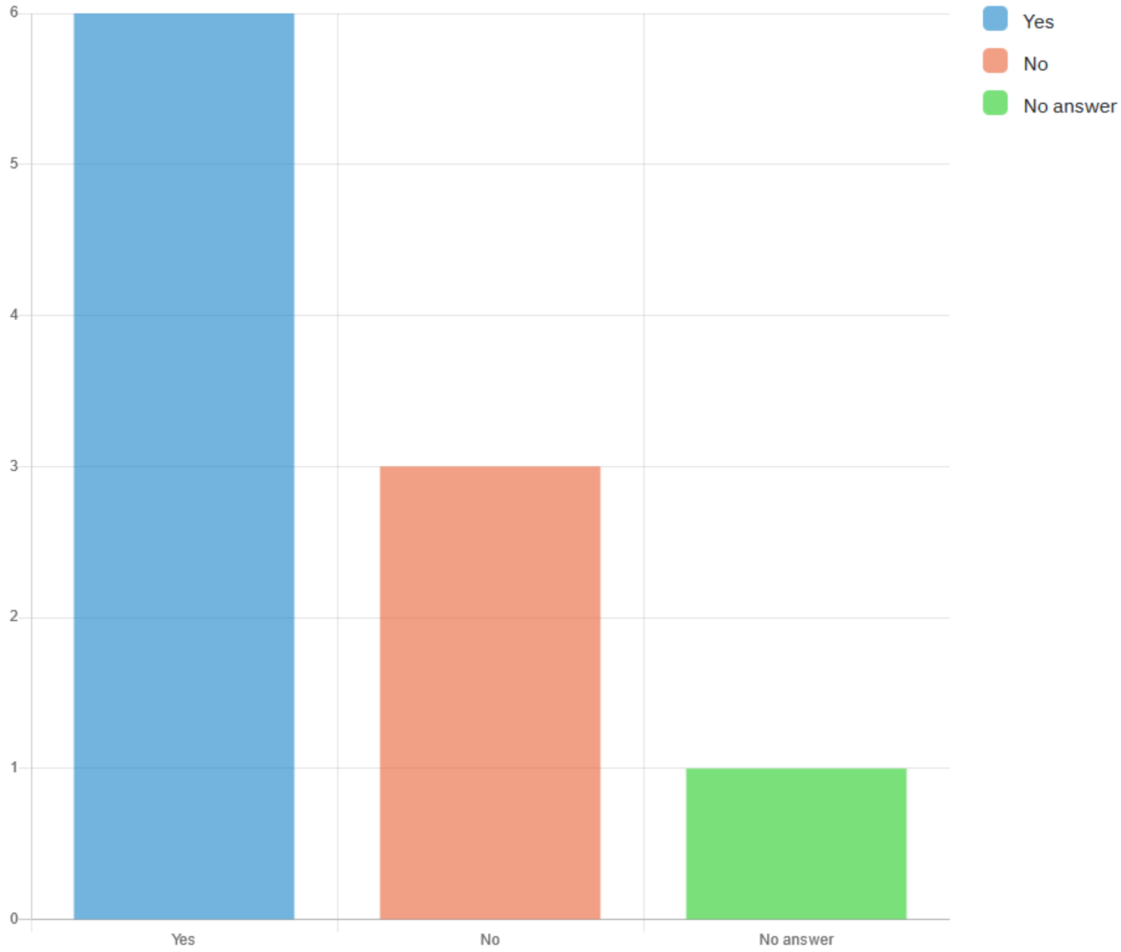

Figure 9 Waste heat recovery investigations

There, it can be observed that more than half of the participating RIs (60%) have already investigated ways for implementing waste heat recovery systems. It is worth noting that 5 of 6 RIs there, are those that already apply or early adopt waste heat reuse techniques. Thus, only one RI investigated the feasibility of implementing waste heat reuse, regardless that this is not applied or planned at the moment.

4.6 Carbon Emissions and Greenhouse Gas (GHG) management

This subsection contains an analysis regarding the carbon emissions and greenhouse gas management performed on the participating RIs. The results showcase that 3 out of 10 (30%) RIs participated in the survey, holistically taking into consideration and measuring their total carbon footprint. This consideration includes:

- **Scope 1:** Emissions that occurred from sources that RI owns.
- **Scope 2:** Emissions that indirectly occurred from the RI.
- **Scope 3:** Any emissions that are not included in Scopes 1 & 2.

Regardless of the participating RIs' ability/option to measure their total carbon footprint, Figure 10 shows the representative estimations of the primary source of carbon emissions on their RI.

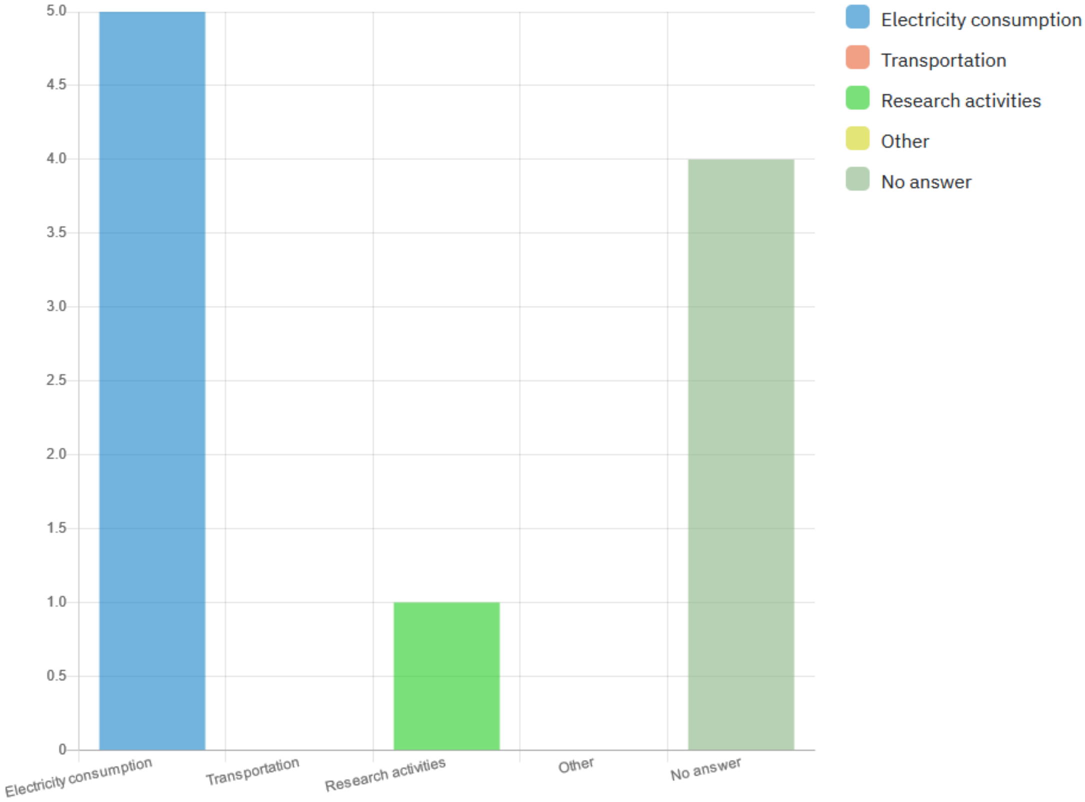

Figure 10 Primary sources of carbon emissions

The results state that 5 out of 10 (50%) stated that electricity consumption is the primary source of carbon emissions, while 1 RI (10%) stated that this occurred from research activities. The rest of the RIs did not provide an answer to that.

The answers provided in Figure 11, show that the RIs intensively (60%) consider **strategies for reducing carbon footprint**, whether they measure it or not, by applying measures like energy efficiency upgrades, renewable energy procurement, or sustainable procurement practices.

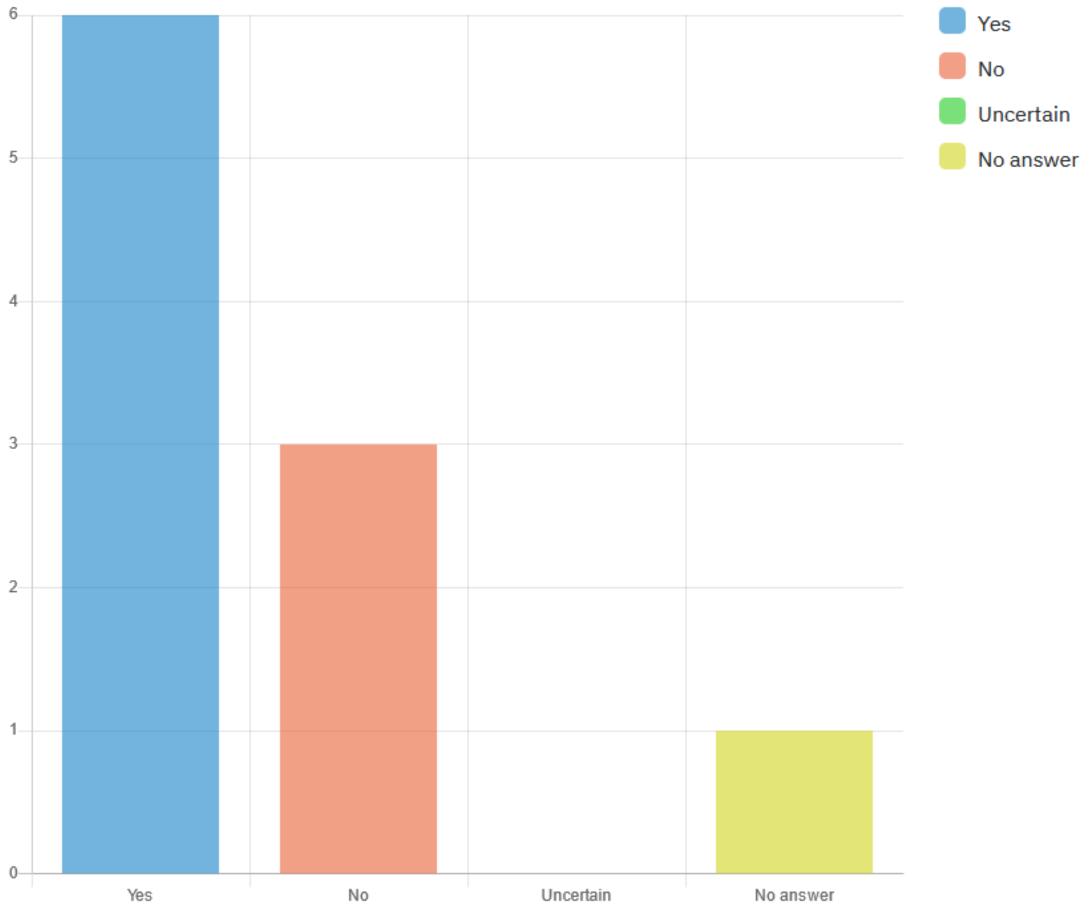

Figure 11 Strategies for reducing carbon footprint

Similarly, a slightly lower number of RIs (5 out of 10) already performed investigations for on-site renewable energy generation (e.g., solar panels) to reduce reliance on grid electricity.

4.7 Waste Management and Recycling

Based on the responses collected, the following results can be extracted for RIs waste reduction. More specifically, only 4 out of 10 (40%) declare that their RI does not have a program (or do not specify other) in place to **promote waste reduction at source**. Figure 12 represents the techniques applied by the participating RIs, to achieve waste reduction at source.

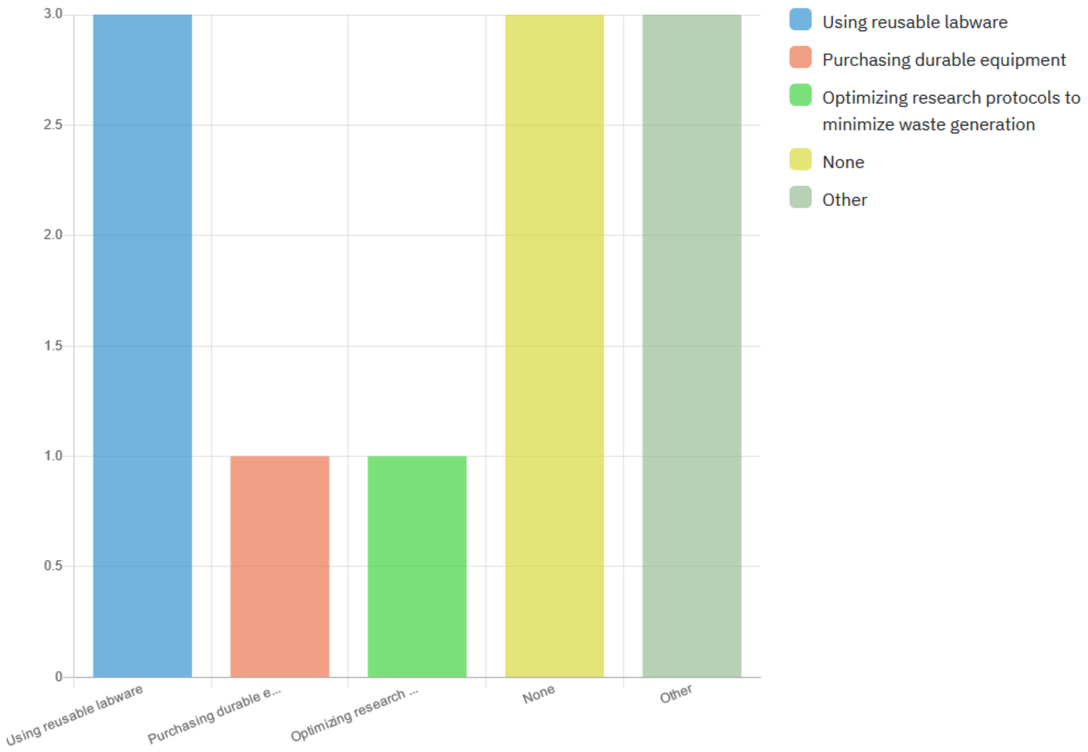

Figure 12 Techniques for waste reduction at source

For those who apply such techniques, the utilization of reusable labware was the most popular answer (30%), while other ways, such as:

- Sorting the waste - reducing the amount of mixed waste
- Decommissioning older equipment in line with new upgrades.

Others noted the application of different techniques based on each node size and strategy. Finally, it is also stated that only 2 out of 10 (20%) RIs completed the survey mentioning that the RI provides training / guidance to the researchers for waste minimization.

4.8 Water usage

The current subsection provides information which regards to **water usage tracking**, **total water withdrawal tracking** and **alternative sources of water investigation**. Specifically, 3 out of 10 (30%) of the participating RIs, mention that they apply both water usage and total water withdrawal tracking, 1 out of 10 (10%) stated uncertainty, while the rest (60%) mentioned that they do not perform such operations. In addition, only 1 out of 10 (10%) investigates the use of alternative water sources for certain uses. Finally, only 1 out 10 RIs can calculate its water footprint.

4.9 RIs Actions per topic

Finally, Figure 13 summarizes the number of RIs which take actions on specific topics.

GreenDIGIT

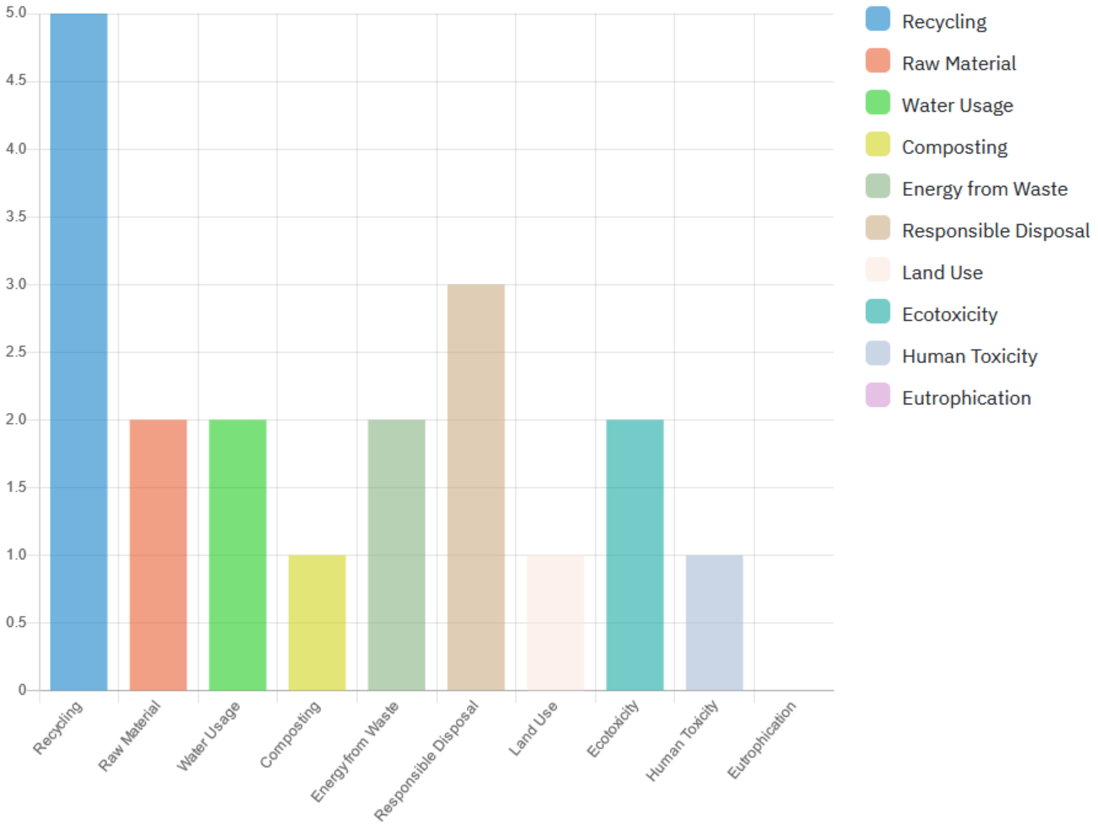

Figure 13 Actions per topic

Indicatively, the specific answers mentioned per topic can be summarised as follows:

- Recycling
  - Sorting plastic, wood, glass, paper waste and electrowaste separation. There were cases in which this is applied either from RI by choice, or through structured programs
  - Circular economy of older equipment
  - Applying recycling concepts like (https://www.swico.ch/en/recycling/)
- Raw Material
  - Circular economy of older equipment
  - IT waste is sent for recycling to certified external company
- Water usage
  - Cooling is operated by a closed circuit. Water consumption is limited to add to the circuit in case of leaks or overflows. River cooling technique reuses Hydro Production of waterfall water
- Composing
  - Organic waste that is generated only in office settings gets partly composted
  - The collection of food and coffee for composting is also applied
- Energy from Waste
  - Excess heat from water. Biogas is produced with this kind of waste
- Responsible Disposal
  - Old equipment is removed via specialized waste treatment companies
  - Recycling oil and diesel generator fluids, batteries, and spare parts as foreseen
- Land Use
  - Planting trees, fruit, and ornamental shrubs in the facility area

- Ecotoxicity
  - Disposing hazardous chemicals and materials contaminated by hazardous chemicals as dangerous waste
  - Recycling oil and diesel generator fluids, batteries and spare parts as foreseen
  - Collection of chemicals
- Human Toxicity
  - Disposing hazardous chemicals and materials contaminated by hazardous chemicals as dangerous waste

4.10 Concluding questions of the survey

Finally, this section of the survey summarizes some outcomes which can be exported through some questions.

Q1: What good practices would you highlight in your specific RI that could lead to broader adoption?

The good practices can be abstractly separated into 3 categories based on the answers given ("**Software / Hardware use-replacement**", "**Personnel**" and "**Other practices**"). Initially, the adoption and promotion of energy monitoring software / KPIs, the cloud outsourcing and the utilization of green energy sources (photovoltaics, waste heat reuse etc.) can be noted as the most prevalent ways that there were pointed out at the survey submissions. Additionally, there were also several answers that included the replacement of non-energy efficient equipment like old lighting systems, central cooling compressors, and air conditioning maintenance. Furthermore, raising awareness, defining policies and aiming at specific sustainable development goals, were the answers to inform and motivate the personnel of RIs. Finally, travel reduction and carbon offsetting were some other good practices that were noted.

Q2: What are the possible opportunities for your specific RI to further strongly address environmental sustainability and lower impact?

In this question, the answers noted as possible opportunities were fully aligned with the good practices mentioned in Q1. Here, more detailed answers were given specifically based on the type of each RI. For example, RIs that deal with Large Language Models (LLMs), can see possible opportunities on avoiding duplicate / multiple training and proper fine tuning, as this is expected to have a large impact on energy efficiency. Moreover, some additional opportunities can be found in the renovation of buildings and the strategic location selection for the infrastructures (e.g. data centers). Finally, the raising of personnel awareness and proper training were also stated here as a potential opportunity. Additionally, more homeworking was also noted in the responses as well.

Q3: Investment in Research and Development: (for energy efficiency and carbon reduction). What percentage of your budget is allocated to R&D for energy efficiency?

At this point, 5 out of 10 RIs representatives provided a specific number for the percentage of their budget that is allocated R&D for energy efficiency. The results show an average of 3.3%, with the submitted values ranging from 0 - 5% in all responses.

Q4: How do you ensure compliance with national or international/EU energy efficiency standards?

The list below contains a summary of measures applied on how each RI ensures compliance with international / EU energy efficiency standards:

- Rely on suppliers.
- Handled on higher level institutions.
- Conducting studies / collecting information regarding national and EU compliance.
- According to university policies.
- Hosting infrastructures at a third-party colocation providers.

There were also cases where RIs responded that they do consider compliance with standards at this point.

Q5:* *What standards do you identify as important for your RI?

Following Q4 the standards which were identified as important for the RIs that participated in the survey can be summarized as follows:

- ISO 9001, ISO 27001
- ISO/IEC 50001
- Tier data center standards
- Uptime Institute Tier Operation; EU directives and good practices

While others also identified general national and European legislative requirements as important. Finally, there were cases where the standards compliance and recommendations will be considered and exported through research projects like GreenDIGIT.

Q6:* *How is staff engagement in energy efficiency initiatives measured and encouraged?

Except for the answers that were personnel oriented and included in questions (Q1 and Q2), this one contains some additional ways applied from the RIs, for engaging and encouraging the staff to participate in energy efficiency initiatives. More specifically, they also note that the involvement of the personnel in wider sustainability initiatives and in R&D is important to engage and encourage staff to the right energy efficiency direction. However, again here the regular training and the knowledge sharing were highlighted again by the participated RIs.

Q7:* *Collaboration with External Entities: (for sustainability initiatives). Do you collaborate with other organizations or consortia on energy efficiency initiatives?

Finally, multiple collaborations were noted by the participants and that they performed through projects (FlexRICAN, GreenDIGIT etc.), involvement in committees, and collaboration with organizations / RIs (indicatively GEANT, EOSC, EGI etc.).

5 Identified gaps and needs

5.1 Gaps in our data

Through the survey, we managed to gather Input from 3 DIGIT RIs that are on the ESFRI Roadmap, from EGI and GÉANT, two European e-Infrastructure with the most prominent provider network, from CERN, an EIRO with a large IT center, from thematic ESFRIs in language sciences (CLARIN) and laser physics (ELI-BEAMS), and from two national/regional IT operators (Switch, University of Freiburg).

Despite our repeated efforts, we were unable to obtain responses from additional ESFRIs that we suspect operate or utilize significant IT or digital infrastructures. We believe that the lack of responses, or in some cases the decision to ‘opt out,’ may be partly due to a lack of initiatives and understanding within RIs regarding the environmental impact of their digital services. If this assumption is correct, it underscores the importance of GreenDIGIT’s future findings for the entire RI landscape.

HPC centers, particularly EuroHPC sites, were notably absent from our survey despite being critical stakeholders due to the scale of these infrastructures. While we continue efforts to engage with at least some EuroHPC sites, we already have access to indirect indicators regarding the environmental impact of European HPC systems. These indicators are derived from publicly available lists such as the TOP500, which ranks the 500 most powerful non-distributed computer systems globally, and the GREEN500, which ranks the same systems based on energy efficiency.

From these lists, we observe that 15 European systems are among the top 50 on the TOP500 list, while 28 European systems rank within the top 50 on the GREEN500 list. This highlights Europe’s strong commitment to procuring and operating energy-efficient HPC systems compared to the rest of the world.

5.2 Policy and governance gaps

The responses were received from RIs that are at different stages of their implementation. While most of the respondents are in full operation and then have more limited options to introduce environmental sustainability-related aspects into their operation, some respondent RIs are still in design, prototyping or pre-production phases, with significant investments to go into procurements and deployments in the coming years. Solutions, such as recommendations, policy templates, education, and assessment frameworks, will be therefore required for RIs through their entire lifecycle. GreenDIGIT will develop solutions through the entire RI lifecycle, and, and for the maximum adoption, the vocabulary used in these solutions should match the lifecycle definitions of ESFRI.

5.3 Resource efficiency gaps

Based on the responses, we can identify three gap areas where digital RIs should seek for improvements to achieve higher resource efficiency:

1. Physical upgrades (building, HW Infrastructure, lightning, renewable supplies, etc.)
2. Software upgrades (data center automation, shutting down unused VMs/racks/lights, robots, user workflow optimisation, etc.)
3. Changing staff behaviour (less travel, recycling, waste management, outsource vs. own, etc.)

GreenDIGIT can support all 3 areas with assessment frameworks, recommendations, standards, training, templates. GreenDIGIT will provide real deployable solutions to the 2nd area through the WP5, 6, 7 activities in 2025-26.

Energy efficiency is clearly the main concern and the main environmental impact contributor in digital RIs. At the same time coherent metrics and infrastructure to trace energy consumption are lacking. GreenDIGIT will develop and will supply solutions here from WP4 and WP6.

Environmental impact analysis beyond energy consumption is often unexplored within digital service providers (e.g., carbon footprint, water usage, waste reuse, and travels). GreenDIGIT can perform deeper research into these aspects, for example by studying how much is the environmental impact of staff travels compared to running computers? - Helping RIs make appropriate policies for remote working, f2f/remote meetings, and investment decisions (e.g. into data center procurements and automation).

5.4 Software infrastructure gaps

Software, and software-based optimisation of digital services seem to be limited at the moment to data centre operation automation (e.g. identify and shut down idle/unused VMs). Higher level software tools for user workflow optimization are not in place and indicate a gap in the landscape for GreenDIGIT to fill. Particular opportunities matching GreenDIGIT plans are in

1. Metrics collection infrastructure to gather environmental impact-related data from digital services and data centers in real time (WP4).
2. Workflow engines optimised for low-energy execution of workloads on distributed/federated services (WP6).
3. Workload delaying systems that, based on the 'greenness' of the procured energy can decide about the best time of job execution considering the carbon footprint of the supplied power (WP6).
4. End-user interfaces displaying predicted/actual environmental impact of digital workflows, enabling the users to make informed decisions on execution and resource allocation (WP5).
5. Reproducibility frameworks that can help eliminate recalculations and can restore results from histories (WP5).

5.5 Skills and collaboration gaps

While RIs overall are aware and are fundamentally concerned about their environmental impact, training and other forms of education, especially in a holistic way, are rare. GreenDIGIT has an opportunity in this respect and will define and deliver awareness raising and education/training programs for the most important stakeholders:

1. For digital service providers (acting on design, implementation, operation, decommissioning).
2. For digital service users (acting on the consumer side, but indirectly influencing the end-to-end environmental impact).

The project should also consider the setup of a knowledge sharing platform (either a digital or, e.g., as series of f2f events) to connect digital service providers on this subject and to facilitate direct information sharing among them.

6 Opportunities, barriers and good practices

6.1 Opportunities

6.1.1 Life cycle management

Life cycle management of digital infrastructure refers to the structured approach to managing the entire lifespan of a digital system or infrastructure - from its initial planning and design to its implementation, operation, maintenance/upgrade, and decommissioning or recycling. The goal is to ensure the infrastructure remains efficient, reliable, and sustainable throughout its lifecycle, while minimising environmental impact and optimizing costs. This is included by ESFRI in the new dimension in the scientific case, called "Environmental considerations".

In the context of digital research infrastructures (RIs), life cycle management presents an overarching opportunity to assess and ensure the environmental sustainability of infrastructure, ensuring that hardware and equipment are used efficiently, maintained, refurbished, reused, or recycled at the end of their operational life. Efficient monitoring of software products and, in particular, scientific applications throughout their lifecycle involves systematically observing, measuring, and analysing the software's performance, functionality, and compliance from development to decommissioning. The goal is to ensure optimal performance, reliability, security, and alignment with business objectives while minimising downtime, resource consumption, and operational costs

An environmental life cycle assessment (LCA) provides a systematic methodology to assess possible environmental impacts of goods, networks and services. The LCA has been internationally standardized in the ISO 14040 standard, which consolidates methodologies of the LCA.[5] The ITU-T recommendation L. 1410 further adapts the standardized LCA methodology specifically for the context of information and communication technology (ICT) goods, networks and services.[6] The LCA aims to form an analysis of the life cycle of infrastructure, to compare results with similar services in the industry, report on the outcomes, and thereby move towards the goal to minimize the negative environmental impacts.

The analysis of GreenDIGIT survey results reveals diverse actions and varying levels of commitment to environmental sustainability among RIs. The findings show differences in practices related to procurement, waste management, and equipment reuse. While some RIs have initiated waste management programmes and recycling efforts, some lack formalized programmes for promoting sustainability through life cycle management. This presents multiple opportunities for improvement.

One key opportunity lies in the adoption of **circular economy approaches** to the management of RIs in line with the EU's circular economy action plan (CEAP). Circular economy refers to "an industrial economy that is restorative or regenerative by intention and design", a closed loop of material flow where economy moves from a linear to a circular model.[7] Circular economy, as a life cycle management system, should consider the source and disposal of material flows, including sourcing renewable energy, and designing and acquiring resilient infrastructure that can be used again with minimal energy

[5] ISO 14040:2006
[6] ITU-T Rec. L.1410
[7] Ellen Macarthur Foundation (2013). *Towards the circular economy Vol. 1: Economic and business rationale for an accelerated transition.*

and high quality retention.[8] The introduction of programmes focused on equipment reuse, refurbishment, and recycling at the end of its life cycle (e.g., donate to partner institutes in less developed regions) can significantly reduce environmental impact and contribute to the adoption of circular economy practices in the industry. By embracing circular economy management practices, RIs can avoid unnecessary waste disposal and minimize their overall footprints.

Sustainable procurement policies also present a major opportunity for RIs. By incorporating environmental impacts as a selection criterion for design architecture, and prioritizing the purchase of durable, energy-efficient, and recyclable equipment, RIs can reduce their long-term environmental impact and carbon footprint and promote operational- and cost-efficiency.

Waste management at the source is another area where RIs can enhance their sustainability efforts. Waste management should, where relevant, incorporate recycling, composting, and sustainable disposal initiatives to ensure hazardous chemicals are safely discarded with no environmental consequences due to possible toxicity. While some of the surveyed RIs actively sort materials like plastic, wood, glass, and electronic waste, others lack structured recycling efforts altogether. By introducing waste management programmes, RIs can reduce waste generation from the outset, ensuring more sustainable operations in the long term.

6.1.2 Energy efficiency and optimization

Energy efficiency and optimization present significant opportunities for RIs to minimize their environmental impact and carbon footprint, particularly in consideration of data centres and networks, which are significant contributors to energy consumption.[9]

Energy-efficient hardware and data centres: The GreenDIGIT survey responses indicate that many RIs recognize data centres as the primary sources of energy consumption. Despite this, energy efficiency measures remain limited in scope, with few RIs tracking their energy usage comprehensively or implementing energy efficiency policies. Improvements to data centres may involve better cooling systems, server consolidation, and dynamic power scaling, all of which can minimize energy consumption. Several respondents have already implemented or are planning to adopt these strategies, such as replacing outdated energy-intense equipment, using direct liquid cooling to reduce the energy required for cooling systems, switching off parts of infrastructure during high demand, and using LED lighting to reduce power consumption. Some RIs are also considering or already implementing GPU job scheduling and workflow optimization to enhance efficiency, especially within high-performance computing (HPC) operations. Another low-hanging fruit is to avoid duplicate or multiple training models with the same data sets by sharing know-how among data centres.

Renewable energy transition and CO2 reduction: To reduce the carbon footprint of operations, RIs should transition to the use of renewable energy solutions, such as solar panels, wind power, or hydroelectric energy. While some surveyed RIs reported on installations of photovoltaic panels on-site, green energy sourcing, and are planning to increase their use of renewable energy in operations, many still rely mostly or exclusively on traditional fossil fuel energy sources.[10] Most surveyed RIs also did not report any CO2 measurement mechanisms to give further insights into the carbon emission impacts of energy use. Establishing renewable energy goals and annual CO2 measurements to estimate

[8] Ellen Macarthur Foundation (2013).
[9] In the scope of results analysis from GreenDIGIT landscape surveys.
[10] In the scope of results analysis from GreenDIGIT landscape surveys.

climate impacts will pave the path for larger-scale change potential. One respondent also reported on preparing a project for carbon offsetting to mitigate climate impacts further. By expanding these initiatives, RIs can drastically reduce their carbon emissions.

Waste heat recovery: Waste heat generated during RI operations presents another area of opportunity. While some surveyed RIs reported ongoing actions to reuse waste heat for heating buildings, several RIs reported significant waste heat production but have not yet implemented systems for capturing or reusing the heat. Various heat recovery technologies exist to capture waste energy generated from operation processes, which can be transferred back to the system to generate electrical and mechanical power or repurposed for additional heating purposes.[11] Waste Heat Recovery (WHR) systems for data centres and RI computer, storage and communication nodes should be adapted according to the different ranges of waste heat temperatures (typical waste temperatures in datacenters often range between **25°C and 45°C (77°F to 113°F))** and according to the type of need.[12] Data centres are using different cooling systems: Computer room air conditioning (CRAC), Computer room air handling (CRAH), and liquid cooling. It is important to mention that WHR systems have higher recovery potential with higher source temperature at the level of 40-50 C (up to 50-60 C) what can be achieved in CRAH and liquid cooling.[13] By adopting appropriate waste heat recovery technologies, RIs can repurpose heat to reduce their overall energy consumption.

6.1.3 Policy and regulatory alignment

Policy and regulatory alignment is a crucial area for improving sustainability in RIs. Compliance with national, European, and international standards on energy efficiency and sustainability practices offers RIs both challenges and opportunities. By integrating sustainability metrics into evaluation frameworks and exploring the use of sustainability certifications, RIs can demonstrate and communicate environmentally responsible practices in the field.

Incorporation of sustainability metrics: The integration of sustainability metrics remains a key area for development within RIs. Several respondents to the GreenDIGIT survey indicated that their infrastructures currently lack a comprehensive system for tracking and reporting energy efficiency or carbon emissions. However, some respondents reported using specific metrics to track energy efficiency, with Power Usage Effectiveness (PUE) being the most common. Other metrics, such as Watts per virtual machine (VM), Watts per graphics processing unit (GPU), or FLOPS per Watt, are also employed. Some RIs monitor energy consumption on an annual basis, comparing scientific and operational usage. There is a clear opportunity to establish standardized energy monitoring systems, which could be embedded into dashboards or research tools to assist both operators and researchers in reducing energy usage. Energy consumption metrics, such as kilowatt constant draw, can also be used to convert tracked energy usage into approximate carbon emission tonnes. Tracking carbon

[11] Harnessing waste heat: The imperative shift for data centers Why the pursuit of net-zero hinges on the data center’s ability to harness waste heat. Blog by Benjamin Lépineux, ENGIE, November 30, 2023 [online] https://www.datacenterdynamics.com/en/marketwatch/harnessing-waste-heat-the-imperative-shift-for-data-centers/

[12] Xiaolei Yuan, Yumin Liang, Xinyi Hu, Yizhe Xu, Yongbao Chen, Risto Kosonen, Waste heat recoveries in data centers: A review, Journal Renewable and Sustainable Energy Reviews 188 (2023) 113777 [online] https://doi.org/10.1016/j.rser.2023.113777

[13] Xiaolei Yuab, et al (2023).

emissions on an annual basis allows RIs to compare metrics and take actions toward reducing emissions.

Compliance with regulations and certification schemes: Most respondents to the GreenDIGIT survey indicated that compliance with national and European energy standards and regulations is managed by higher-level institutional bodies, such as building infrastructure departments or national nodes. While some RIs reported adhering to energy limits imposed by national regulations, others are in the process of developing policies to address energy consumption and carbon footprint. Certification schemes aiming to assess and certify sustainability measures pose an additional opportunity to demonstrate compliance and build value for both operators and end users. Encouraging alignment with certifications and performance measurements not only validates ongoing efforts but can also foster a culture of continuous improvement in sustainability management.

6.1.4 RI stakeholders' impact

Promoting sustainability among RI stakeholders, including researchers, staff, operators, and end users, is a potential opportunity to extend the environmental impact of RIs beyond direct operations to other indirect impacts related to the upkeep and use of the infrastructure. Engaging personnel through education and training programmes and awareness campaigns can foster a culture of environmental responsibility.

Training and education programmes: Providing training programmes for researchers on sustainability and energy efficiency may include guidance on minimizing waste generation, improving code efficiency, and adopting energy-conscious workflows. Training programmes can also contribute to awareness raising on sustainable practices for staff in general, such as switching off unused equipment and reducing non-essential travel by allowing for hybrid event participation. While some GreenDIGIT survey respondents have begun planning training programmes, many others reported no formal initiatives yet.

Corporate social responsibility (CSR) policies can be used as an opportunity to enforce organisation-wide sustainability actions. For example, one of the survey respondents reported on a CSR policy that dedicates a Green Team to oversee organisational goals, including aiming to reach net zero carbon emissions by 2035. These types of cross-organizational initiatives and utilising global frameworks, like the UN's Sustainable Development Goals (SDGs), can help embed sustainability into the workforce culture and motivate employees to take ownership of green practices.

6.2 Barriers

While several opportunities emerge from the GreenDIGIT survey analysis for RIs' environmental impact mitigation, some barriers may still hinder their full implementation on a wider scale. Barriers refer to the various challenges that hinder RIs from fully adopting the identified sustainable practices, including technical, financial, and operational constraints.

6.2.1 Technical barriers

A major technical challenge remains the reliance on **outdated infrastructure** that is not energy-efficient or designed for sustainability. Upgrading systems, such as servers and cooling units, can be costly and disruptive to operations, posing a challenge to access technologies that would allow for environmentally conscious operations. High-performance computing (HPC) and data-intensive research also require significant energy, increasing environmental impact, particularly when more efficient alternatives are not accessible.

Another barrier emerging from the survey findings is the **lack of specialized tools** for tracking energy consumption and carbon emissions. Several RIs cannot currently measure or optimize their environmental footprint effectively. Moreover, while some institutions plan to transition to renewable energy sources, such as solar panels, logistical and financial hurdles may delay these efforts, including high installation costs, long approval and construction timelines, grid connectivity issues, or lack of standardization and quality control in the industry.[14] One respondent also reported the potential barrier of data protection and privacy requirements that may hinder the possibility of sharing results, resulting in centres having to implement training modules locally rather than through shared know-how.

6.2.2 Financial barriers

Transitioning to sustainable operations in RIs presents significant financial challenges, particularly with **high upfront costs tied to upgrading infrastructure**. This includes, for example, investing in energy-efficient hardware, renewable energy sources, or optimized data centres. For some RIs, outdated facilities or equipment make these investments even more difficult. In the GreenDIGIT survey, one RI, for example, noted the substantial costs of retrofitting an older building and upgrading hardware to meet modern energy standards. Another RI identified capturing and reusing waste heat as a desired solution to energy efficiency, but administrative and contractor costs are making it complex. Beyond the upfront costs, organisations may also face financing hurdles for long-term duration to keep equipment up-to-date, undermining efforts for long-term investment.

However, a culture shift is necessary to mobilise capital for green financing. OECD's report on green financing suggests identifying the "right incentives" to reward long-term performance over short-term problems and positioning upfront investments as a form of **long-term insurance**.[15] The report identifies that financial instruments that manage climate-related risks without altering short-term market exposure can encourage greener investments. These tools can incentivize organisations to integrate environmental and sustainability goals into business models by aligning financial risk management with climate-conscious practices.[16]

6.2.3 Variability in sustainability assessment criteria

Integrating energy consumption monitoring and sustainability into evaluation frameworks can pose challenges for RIs, particularly due to the **varying definitions for measurement methodologies** of environmental impact. Many RIs from the GreenDIGIT survey have not established protocols to track or estimate energy use efficiency. Without regularly measured statistics, it is difficult to assess progress or justify investments in sustainability initiatives. While some infrastructures depend on suppliers to comply with national and EU energy efficiency standards, there exists a clear need for RIs to develop

[14] Payel, Spandan Basak et al. (2023). "Exploring the barriers to implementing solar energy in an emerging economy: Implications for sustainability."
[15] OECD (2017). "Green financing: Challenges and opportunities in the transition to a clean and climate-resilient economy."
[16] OECD (2017).

internal monitoring systems for real-time energy usage insights. Furthermore, measuring renewable energy consumption is complicated by **differing definitions across jurisdictions**, as noted by another survey respondent, underscoring the need for standardized metrics to facilitate effective sustainability assessments.

6.3 Good practices

Adopting sustainable practices in research infrastructures should involve a combination of strategies to target the whole RI life cycle, including:

1. **Use less:** Reducing energy and resource consumption is central to sustainable RI management. This can be achieved through building modern, energy-efficient infrastructure, optimizing software for energy-conscious workflows, using LED lighting, minimizing travel, and locating data centres in cooler climates or underground to lower cooling needs.[17]

2. **Use renewable energy sources**: Transitioning to renewable energy is a critical step for RIs. By switching to green energy providers or installing on-site solar panels, RIs can substantially lower their carbon footprints.

3. **Reuse and recycle**: Implementing circular economy principles allows RIs to reduce waste and promote reuse. This includes repairing equipment, recycling materials such as paper and plastic, and re-using waste heat for office or building heating, thereby minimizing environmental impact.

4. **Shared infrastructures:** Use shared infrastructures, such as European RIs and e-Infrastructures for digital services, or public transportation for staff commute. Shared Infrastructures bring the economy of scale for resources and for energy efficiency.

5. **Educate and innovate**: Cultivating a sustainability-aware culture within RIs can foster long-term progress. Initiatives may include staff training on sustainable practices, information dashboards to raise awareness, platforms for sharing and developing green innovations, and establishing common goals to strive towards.

6. **Measure and improve**: Effective sustainability management relies on regular updates and analysis of key metrics. This includes tracking, i.e., energy efficiency, carbon emissions, and waste management across operations. Standardized metrics, such as Power Usage Effectiveness (PUE) and other energy-consumption indicators, can provide RIs with actionable insights to guide continuous improvement efforts.

7. **Invest into environmental handprint:** your handprint evaluates your actions that help reduce climate change beyond your own value chain. If a service provider invests into side projects that increase its handprint to the level of its footprint, then it becomes carbon neutral.

This is an initial attempt to collect good practice. A fully elaborated proposal will come in our WP3 deliverable D3.2 in August 2025.

[17] Jiao, Yanmei et al. (2017). "Thermal analysis for underground data centres in the tropics."

7 Conclusion and next steps

This landscape assessment, the first public deliverable of the GreenDIGIT project, will serve as a valuable input for the next two years of work. Through the study, we gained insights into the current adoption of environmentally impactful design and operational practices within the community of Research Infrastructures (RIs) and digital service providers serving European RIs. Additionally, we identified existing practices, opportunities, and challenges or barriers to advancing the RI landscape toward greater environmental sustainability.

The study highlighted key opportunities for GreenDIGIT in the following areas:

1. Policy and Governance: Establishing frameworks for managing the full RI lifecycle.
2. Resource Efficiency: Enhancing efficiency, particularly through advanced software infrastructures.
3. Skills and Collaboration: Building expertise and fostering cooperation within the community.

Preliminary high-level responses to these opportunities have been outlined in this report. A comprehensive approach will be detailed in our next deliverable under WP3, titled "D3.2 Environmental Impact Assessment Methodology and Guidelines for RIs," scheduled for publication in August 2025.

In the interim, we will engage with a broader range of stakeholders to disseminate, validate and extend the findings of this landscape study.

8 References

European Commission – JRC publications

European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), Publications Office of the European Union, Luxembourg, 2024, JRC136475
https://data.europa.eu/doi/10.2760/093662

European Commission, Joint Research Centre, Acton, M., Bertoldi, P. and Booth, J., 2024 Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency, European Commission, Ispra, 2024, JRC136986.
https://e3p.jrc.ec.europa.eu/sites/default/files/documents/publications/jrc136986_2024_best_practice_guidelines.pdf

Commission Delegated Regulation (EU) 2024/1364 of 14 March 2024 on the first phase of the establishment of a common Union rating scheme for data centres, 14 March 2024
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1364&qid=1723470355995

Assessment Framework for Data Centres in the Context of Activity 8.1 in the Taxonomy Climate, Bertoldi P. *Delegated Act , European Commission, Ispra, 2023, JRC131733*
https://e3p.jrc.ec.europa.eu/publications/assessment-framework-data-centres-context-activity-81-taxonomy-climate-delegated-act

ESFRI publications

ESFRI Report on Energy and Supply Challenges of Research Infrastructures, Published July on 5 July 2023 (https://zenodo.org/records/8123921

ESFRI Roadmap Update 2026 - Checklist for dimension "environmental considerations"
https://www.esfri.eu/sites/default/files/ENVIRONMENTAL%20CONSIDERATIONS%20Checklist.pdf

International organisations publications

OECD (2017). "**Green financing: Challenges and opportunities in the transition to a clean and climate-resilient economy.**" *OECD Journal: Financial Market Trends*, Vol. 2016/2: 63-78, https://doi.org/10.1787/fmt-2016-5jg0097l3qhl

United Nations - Net Zero
https://www.un.org/en/climatechange/net-zero-coalition

International standards

European developed standards on data centres design and operation EN 50600

ISO 50001 Energy management systems
https://www.iso.org/iso-50001-energy-management.html

ISO 50002 Energy audits
https://www.iso.org/standard/60088.html

ISO 14002 Environmental management systems - Guidelines for using ISO 14001 to address environmental aspects and conditions within an environmental topic area
https://www.iso.org/standard/70138.html

ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework
https://www.iso.org/standard/37456.html

ISO 30134 Information technology - Data centres key performance indicators
ITU-T Rec. L.1410 (12/2014). *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services.* https://www.itu.int/rec/T-REC-L.1410-201412-I/en.

Technical publications

ARCEP - Enquête annuelle "Pour un numérique soutenable" - édition 2024 (données 2022) - In French only - Annual survey "**For a sustainable digital world"** – 2024 edition (2022 data)
[online] https://www.arcep.fr/u/c8tz-aa4a

ATIS White Paper Green G: The Path Toward Sustainable 6G **[online]**
https://nextgalliance.org/white_papers/green-g-the-path-towards-sustainable-6g/

D7.4 Green Computing progress and improvements within EGI-ACE, report produced by EGI-ACE Task 7.2 and the EGI Green Computing Task force, published on 16/02/2023
https://zenodo.org/records/7670205

Ellen Macarthur Foundation (2013). ***Towards the circular economy Vol. 1: Economic and business rationale for an accelerated transition***.
https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

Energy Efficiency: An Overview - Future Networks. (2019, May 8). GSMA. Retrieved April 3, 2024, from**:**
https://www.gsma.com/solutions-and-impact/technologies/networks/gsma_resources/energy-efficiency-an-overview/

Harnessing waste heat: The imperative shift for data centers Why the pursuit of net-zero hinges on the data center's ability to harness waste heat. Blog by Benjamin Lépineux, ENGIE, November 30, 2023
[online]https://www.datacenterdynamics.com/en/marketwatch/harnessing-waste-heat-the-imperative-shift-for-data-centers/

How to Calculate and Measure Greenhouse Gas Emissions. (2023, July 10). Ecometrica.
Retrieved April 3, 2024, from https://ecometrica.com/knowledge-bank/guides/how-to-calculate-measure-ghg-emissions-guide/

Indicators for Environmental Sustainability**.** Yan Dong, Michael Z. Hauschild. Procedia CIRP 61. (2017): 697-702.
DOI:10.1016/j.procir.2016.11.173

*Jiao, Yanmei et al. (2017). "****Thermal analysis for underground data centres in the tropics.****"*
https://doi.org/10.1016/j.egypro.2017.12.675

*Payel, Spandan Basak et al. (2023). "****Exploring the barriers to implementing solar energy in an emerging economy: Implications for sustainability****." 13th Annual International Conference on Industrial Engineering and Operations Management*
https://doi.org/10.46254/AN13.20230584

The Shift Project - Digital
https://theshiftproject.org/en/category/thematic/digital/

Xiaolei Yuan, Yumin Liang, Xinyi Hu, Yizhe Xu, Yongbao Chen, Risto Kosonen, ***Waste heat recoveries in data centers: A review****, Journal Renewable and Sustainable Energy Reviews 188 (2023) 113777 [online]*
https://doi.org/10.1016/j.rser.2023.113777

Annex A – GreenDIGIT survey

Survey of digital Research Infrastructures practices and needs for environmental sustainability and impact reduction.

Welcome to our questionnaire! In this survey, we will explore the following themes:

- General questions about energy consumption and energy efficiency
- Energy Efficiency
- Impact of Digital Technologies, Notably for Digital Research Infrastructures (RIs)
- Renewable Energy Use
- Waste Heat Recovery
- Carbon Emissions and Greenhouse Gas (GHG) Management
- Waste Management and Recycling
- Water usage
- Other topics
- Concluding questions

Your insights on these topics are valuable and will contribute to our understanding and improvement of these critical areas. We will keep you informed of the results. Thank you for your participation!

Preamble

GreenDIGIT is a project funded by Horizon Europe under the topic HORIZON-INFRA-2023-TECH-01-01 "New technologies and solutions for reducing the environmental and climate footprint of RIs".

GreenDIGIT brings together 4 major distributed Digital Infrastructures at different lifecycle stages, EGI, SLICES, SoBigData, and EBRAINS, to tackle the challenge of environmental impact reduction with the goal to provide solutions that are reusable across the whole spectrum of digital services on the ESFRI (European Strategy Forum on Research Infrastructures) landscape and play a role model.

One of the objectives is to work on "RI Survey and Landscape Analysis for Sustainability and Impact Reduction". To this end, GreenDIGIT collects information from the digital Research Infrastructures (RIs), to identify their practices, approaches, metrics, and tools regarding environmental sustainability and impact reduction.
This data will be used to define a generic model of RI-environment interaction and will also serve as a basis for other tasks and work packages within the project.

The Survey is developed based on existing European and International Regulation, Best Practices and ISO Standards which are summarized in the attached document, where you will also find the indicators and references used in the survey.

In this context, we seek your participation in responding to this questionnaire to gather valuable information for the advancement of the GreenDIGIT project. Your responses will contribute to the development of sustainable solutions and the promotion of best practices within the European research digital infrastructure community. It will also contribute to the development of the digital Ris technical recommendations and policy development.

There are 71 questions in this survey.

Contact information

Your input is invaluable in shapping a greener future for the Digital Research Infrastructures. By participating in this questionnaire, you contribute to guiding our future progress, and we commit to keeping you informed of the developments and outcomes of this collaborative effort.

1 **Name of the contact person** *

Please write your answer here:

2
Email of the contact person
Please enter you e-mail, so that we can contact you in case we would need more information or a clarification.

*

Please write your answer here:

3 Phone number of the contact person

Please write your answer here:

4

What is your role in the infrastructure?

This will help us better understand the context of your responses.

Please write your answer here:

Preliminary questions about your Research Infrastructure

5 Name of Research Infrastructure (RI) *

Please write your answer here:

6 Type of research infrastructure

Choose one of the following answers
Please choose **only one** of the following:

- ESFRI or non-ESFRI ERIC
- International organisation other than ERIC
- National RI open to international users
- National RIs
- Association/network of RIs
- Other

7 What are the primary resources that your research infrastructure mainly offers access to?

Select all that apply
Please choose **all** that apply:

- Scientific equipment or sets of instruments
- Knowledge-related facilities such as collections
- Archives and scientific data
- Computation resources
- Communication networks
- Other:

8 What kind of RI are you?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Single sited
- ◯ Distributed

9 Please name the country, where the Central Hub / Headquarters of your RI is located

Please write your answer here:

10 What is the size of your Research Infrastructure (RI) in terms of the number of served users per year?

Only numbers may be entered in this field.
Please write your answer here:

11 How many data centers does your RI operate?

Please write your answer here:

12 How many servers does your RI currently maintain?

Please write your answer here:

13 What is the total storage capacity of your RI's infrastructure?

Please write your answer here:

14 How many requests does your RI process per day, on average?

Please write your answer here:

General questions about energy consumption and energy efficiency

15 Does the RI track its total energy consumption (electricity, gas, water, etc.)?

Choose one of the following answers
Please choose **only one** of the following:

- Yes
- No
- Partially

16
How is energy consumption monitored and measured?

Only answer this question if the following conditions are met:
Answer was at question ' [G03Q17]' (Does the RI track its total energy consumption (electricity, gas, water, etc.)?)

Choose one of the following answers
Please choose **only one** of the following:

- Smart meters
- Building management systems
- Other

17 Do you have an estimate of your current energy consumption per year, or do you have an idea of the amount of energy you regularly consume in your operations?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Yes
- ◯ No

Make a comment on your choice here:

18 What are the primary factors contributing to the RI's energy consumption?

Select all that apply
Please choose **all** that apply:

- ☐ Data centers
- ☐ Network
- ☐ Cloud/Edge
- ☐ Other:

19 Describe the initiatives taken to decrease your energy consumption

Please write your answer here:

20 What energy efficiency metrics do you use in your infrastructure or data center?

Please write your answer here:

21 Are there any key performance indicators (KPIs) established for energy consumption and efficiency within the RI?

Please write your answer here:

Energy Efficiency

22 Does the RI have a formal energy efficiency policy in place?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

23 Describe the policy?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G04Q25]' (Does the RI have a formal energy efficiency policy in place?)

Please write your answer here:

24 Has the RI conducted any energy audits to identify opportunities for improving energy efficiency?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

25 Has the RI implemented any energy-saving measures?

Select all that apply
Please choose **all** that apply:

- ☐ Upgraded equipment
- ☐ Improved building insulation
- ☐ LED lighting
- ☐ Other:

26 Does the RI have a program to educate and encourage personnel on energy-saving practices?

Please choose **only one** of the following:

- Yes
- No

27 Describe

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G04Q30]' (Does the RI have a program to educate and encourage personnel on energy-saving practices?)

Please write your answer here:

28 On a scale of 1 to 100, how would you rate your energy efficiency? (1 being extremely inefficient and 100 being extremely efficient)

Your answer must be between 1 and 100
Only an integer value may be entered in this field.
Please write your answer here:

29 When choosing the technical architecture for your services, is the environmental impact of the target architecture a selection criterion?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

30 What are your short-term and long-term goals for energy efficiency improvements?

Please write your answer here:

31 Are there any ongoing or planned projects focusing on energy-efficient technologies?

Please write your answer here:

Impact of digital technologies, notably for digital RIs

32 Have you implemented any digital technologies specifically aimed at improving energy efficiency within your operations?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

33 What are the key technical specifications impacting energy consumption? (server types, CPU models, HDD/SSD, ...)

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G05Q36]' (Have you implemented any digital technologies specifically aimed at improving energy efficiency within your operations?)

Please write your answer here:

34 Does your Research Infrastructure (RI) implement scientific workflow optimization strategies to minimize energy consumption?

Please write your answer here:

35 Is there a specific focus on optimizing energy usage within the datacenter job scheduling system?

Please write your answer here:

36 Does your RI engage in cloud outsourcing for on-demand computation tasks to optimize energy usage?

Please choose **only one** of the following:

- Yes
- No

37 How do these digital technologies (improving energy efficiency) impact the quality of your services?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G05Q36]' (Have you implemented any digital technologies specifically aimed at improving energy efficiency within your operations?)

Choose one of the following answers
Please choose **only one** of the following:

- Reduced
- No significant impact
- Improved
- Other

38 What effect do these digital technologies (improving energy efficiency) have on the accessibility to your services?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G05Q36]' (Have you implemented any digital technologies specifically aimed at improving energy efficiency within your operations?)

Choose one of the following answers
Please choose **only one** of the following:

- Reduced
- No significant impact
- Increased
- Other

39 How do these digital technologies (improving energy efficiency) influence the cost of operating your services?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G05Q36]' (Have you implemented any digital technologies specifically aimed at improving energy efficiency within your operations?)

Choose one of the following answers
Please choose **only one** of the following:

- Reduced cost
- Cost-neutral
- Increased cost
- Other

Renewable Energy Use

40 Does the RI utilize any renewable energy sources (e.g., solar panels, wind turbines, green energy suppliers)?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Yes
- ◯ No

Make a comment on your choice here:

41 Is it measured?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

42 How is it measured?

Please write your answer here:

43 What percentage of the RI's total energy consumption comes from renewable sources?

Only numbers may be entered in this field.
Your answer must be between 0 and 100
Please write your answer here:

44 Is the RI exploring additional opportunities to increase its use of renewable energy?

Please choose **only one** of the following:

- Yes
- No

45 What specific options are being considered?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G06Q50]' (Is the RI exploring additional opportunities to increase its use of renewable energy?)

Please write your answer here:

Waste Heat Recovery

46 Does the RI generate any significant amount of waste heat from its operations (e.g., from cooling systems, high-performance computing)?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

47 Are there any existing solutions in place to capture and reuse waste heat?

Please write your answer here:

48 Has the RI investigated the feasibility of implementing waste heat recovery systems?

Please choose **only one** of the following:

- Yes
- No

Carbon Emissions and Greenhouse Gas (GHG) Management

49 Does the RI measure its total carbon footprint (including Scope 1, Scope 2, and Scope 3 emissions)?

Please choose **only one** of the following:

- Yes
- No

50
What methodology is used to calculate the RI's carbon footprint (e.g. international standards like GHG Protocol)?

Only answer this question if the following conditions are met:
Answer was 'Yes' at question ' [G08Q55]' (Does the RI measure its total carbon footprint (including Scope 1, Scope 2, and Scope 3 emissions)?)

Please write your answer here:

51 Has the RI's total carbon footprint increased, decreased, or remained stable over the past 5 years?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Increased
- ◯ Decreased
- ◯ Remained stable

52 Does the RI collect and analyze data on its carbon emissions across all scopes?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

53 Are there any established key performance indicators (KPIs) for carbon emissions reduction within the RI?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

54 What is the current estimation of your RI's carbon footprint, expressed in metric tons of CO2 equivalent?

Please write your answer here:

55 What are the primary sources of carbon emissions within the RI?

Choose one of the following answers
Please choose **only one** of the following:

- Electricity consumption
- Transportation
- Research activities
- Other

56 Does the RI have a formal GHG management plan in place?

Please choose **only one** of the following:

- Yes
- No

57 What are the key goals of the plan?

Choose one of the following answers
Please choose **only one** of the following:

- ◯ Reduction in carbon emissions
- ◯ Achieving carbon neutrality
- ◯ Other [ ]

58

Please choose the appropriate response for each item:

	Yes	Uncertain	No
Has the RI implemented any strategies to reduce its carbon footprint (e.g., energy efficiency upgrades, renewable energy procurement, sustainable procurement practices)?	○	○	○
Are there any adopted or recommended carbon offset initiatives by your research infrastructure?	○	○	○
Has the RI identified and quantified its Scope 1 emissions (e.g., on-site fossil fuel combustion, fugitive emissions)?	○	○	○
Does the RI provide opportunities for researchers to consider the carbon footprint of their research activities?	○	○	○
Are there opportunities to reduce Scope 1 emissions by switching to cleaner fuels, improving building efficiency, or optimizing vehicle usage?	○	○	○
Has the RI investigated on-site renewable energy generation (e.g., solar panels) to reduce	○	○	○

	Yes	Uncertain	No
reliance on grid electricity?			
Does the RI have any strategies in place to address and potentially reduce its Scope 3 emissions (e.g., collaboration with low-carbon suppliers, encouraging sustainable travel practices, ...)?	◯	◯	◯

Waste Management and Recycling

59 Does the RI have a program in place to promote waste reduction at source?

Select all that apply
Please choose **all** that apply:

- ☐ Using reusable labware
- ☐ Purchasing durable equipment
- ☐ Optimizing research protocols to minimize waste generation
- ☐ None
- ☐ Other: ____________

60 Does the RI provide training or guidance to researchers on waste minimization techniques?

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

Water Usage

61 **Water Usage**

Please choose the appropriate response for each item:

	Yes	Uncertain	No
Does the RI track its "water consumption"?	○	○	○
Does the RI calculate its water footprint?	○	○	○
Does the RI track its total "water withdrawal"?	○	○	○
Does the RI calculate Water Usage Effectiveness WUE?	○	○	○
Does the RI generate wastewater differently than "urban wastewater" generated from domestic activities (i.e. industrial wastewater)?	○	○	○
Has the RI investigated the use of alternative sources of water for certain uses (i.e. rain, regenerated...)?	○	○	○

Regarding the following topics: do you take actions ? If yes, please explain what actions ?

62

Comment only when you choose an answer.
Please choose all that apply and provide a comment:

- [ ] Recycling
- [ ] Raw Material
- [ ] Water Usage
- [ ] Composting
- [ ] Energy from Waste
- [ ] Responsible Disposal
- [ ] Land Use
- [ ] Ecotoxicity
- [ ] Human Toxicity
- [ ] Eutrophication

Concluding questions

63 What good practices would you highlight in your specific RI that could lead to broader adoption?

Please write your answer here:

64 What are the possible opportunities for your specific RI to further strongly address environmental sustainability and lower impact?

Please write your answer here:

65 Investment in Research and Development: (for energy efficiency and carbon reduction). What percentage of your budget is allocated to R&D for energy efficiency?

Only numbers may be entered in this field.
Your answer must be between 0 and 100
Please write your answer here:

66 How do you ensure compliance with national or international/EU energy efficiency standards?

Please write your answer here:

67 What standards do you identify as important for your RI?

Please write your answer here:

68 How is staff engagement in energy efficiency initiatives measured and encouraged?

Please write your answer here:

69 Collaboration with External Entities: (for sustainability initiatives). Do you collaborate with other organizations or consortia on energy efficiency initiatives?

Please write your answer here:

Final questions

70 Any other comments, issues, recommendations on this topic?

Please write your answer here:

71 By submitting this form, I agree that my responses to the questionnaire can be published. *

Choose one of the following answers
Please choose **only one** of the following:

- I confirm
- I would like to assure you that all information provided will be kept anonymous and confidential.

Submit your survey.

Thank you for completing this survey.

Annex B – GreenDIGIT survey references

This document was provided to the survey respondents as an annex to the survey.

The link to this document (referred to as the "attached document") was included in the preamble of the survey in the following paragraph:

The Survey is developed based on existing European and International Regulation, Best Practices and ISO Standards which are summarized in the attached document, where you will also find the indicators and references used in the survey.

GreenDIGIT Survey References

Content Table

1. Indicators for environmental sustainability and lowering impact

In this section, we will describe the indicators identified by the Joint Research Centre (JRC) in the report "Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)"[1].

Initially, we will present the five main categories of indicators, each of which will be divided into subcategories.

1.1. Energy Consumption and Management

This category focuses on the consumption and management of energy resources. It encompasses measures such as the total energy consumed, the efficiency of energy usage, utilisation of renewable energy sources, and strategies for recovering waste heat generated during energy production or consumption.

1.1.1. Energy consumption

Energy consumption is the total amount of power used over a set period, typically measured in Watt-hours (Wh), which represents the integral of power consumption over time (e.g., one hour).

1.1.2. Energy efficiency

Energy efficiency refers to the ratio of useful energy output to the total energy input in a system or process. It represents how effectively energy is utilised to achieve a desired outcome or perform a specific task while minimising waste and reducing unnecessary consumption. Higher energy efficiency implies that less energy is required to accomplish the same level of output, leading to cost savings, reduced environmental impact, and improved sustainability. Measures to enhance energy efficiency often involve adopting energy-efficient technologies, optimising processes, improving insulation, and implementing energy management strategies.

1.1.3. Use of renewable energy

The use of renewable energy refers to the incorporation and exploitation of energy derived from naturally replenishing sources such as solar, wind, hydroelectric, biomass, and geothermal energy. This utilisation involves converting these energy sources into usable forms such as electricity, heat, or mechanical energy.

The general formula to calculate it is as follows:

$$Renewable\ Energy\ Utilisation\ (\%) = \left(\frac{Renewable\ Energy\ Used}{Total\ Energy\ Consumption}\right) x\ 100$$

1.1.4. Waste heat recovery

Waste heat recovery (WHR) refers to the process of capturing and reusing heat that is generated as a byproduct in various industrial processes or in heating, ventilation, and air conditioning

[1] European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/093662, JRC136475.

(HVAC) systems. This recovered heat can then be utilised for heating water, preheating air, generating electricity, or other purposes, instead of being released into the environment as waste.

The amount of recovered waste heat can be quantified through various methods:

- **Energy metres:** Metres installed on waste heat sources and usage points measure the amount of transferred energy.
- **Temperature sensors:** Sensors track temperature differences between the inlet and outlet of the WHR system.
- **Modelling:** Computer models estimate the available waste heat and its recovery potential.

1.2. Carbon Emissions and Greenhouse Gas (GHG) Management

Carbon emissions and GHG management refer to the systematic approach taken by organisations, industries, and governments to measure, regulate, and reduce the release of carbon dioxide and other greenhouse gases into the atmosphere. This involves implementing strategies to minimise emissions, enhance energy efficiency, transition to cleaner energy sources, and offset remaining emissions through carbon capture or other means.

1.3. Subcategories of Carbon Emissions

Scope 1: Direct emissions from sources owned or controlled by the organisation, such as emissions from burning fossil fuels for transportation, electricity generation, and heating.

- Fossil fuel combustion for on-site heating, cooling, and electricity generation.
- Fugitive emissions from air conditioning and refrigeration systems.
- Emissions from research infrastructure-owned service vehicles.

Scope 2: Indirect emissions from the consumption of purchased electricity, steam, heat, or cooling.

- Emissions associated with purchased electricity, whether from renewable or non-renewable sources.
- Emissions linked to the consumption of purchased heat or steam.

Scope 3: Other indirect emissions occurring throughout the organisation's value chain, both upstream (suppliers' emissions) and downstream (customers' emissions).

- Emissions from staff business travel (aeroplanes, trains, etc.).
- Emissions arising from purchasing goods and services necessary for the infrastructure's operation.
- Emissions from construction, renovation, and maintenance of buildings and equipment.

1.4. Waste Management and Recycling

1.4.1. Waste Reduction at Source

Minimising the amount of waste produced in the first place, by prioritising the purchase of durable products and optimising processes.

1.4.2. Waste Sorting and Recycling

Waste sorting and recycling are integral components of waste management aimed at reducing the environmental impact of solid waste by maximising the recovery of recyclable materials. Waste is sorted into different categories based on its composition and recyclability, ranging from paper, cardboard, glass, plastic, metal to organic waste.

1.4.3. Composting

Composting initiatives (RI) involve organised efforts to promote and facilitate the transformation of organic waste into compost for soil amendment purposes. These initiatives typically include various activities and programs aimed at encouraging composting practices among individuals, communities, businesses, and institutions. Key components of composting initiatives may include:

- Education and Outreach: Recycling initiatives disseminate information about composting benefits through workshops, materials, and online resources, aiming to boost awareness and engagement.
- Infrastructure Development: Composting initiatives establish facilities and collection systems to efficiently process organic waste, crucial for expanding composting efforts and ensuring accessibility.
- Policy and Regulation: Recycling initiatives advocate for policies and incentives supporting composting integration into waste management, fostering program growth and organic waste diversion.
- Partnerships and Collaboration: Composting initiatives foster collaborations between stakeholders, leveraging resources and expertise to enhance program effectiveness and community engagement.
- Monitoring and Evaluation: Recycling initiatives conduct ongoing assessment of composting programs, tracking metrics like participation and compost quality to inform decision-making and optimise outcomes.

1.4.4. Energy-from-Waste

Involves incinerating non-recyclable waste to produce energy, such as electricity or heat. This approach reduces landfill waste while generating useful energy. Within recycling initiatives, Energy-from-Waste can be seen as part of an integrated waste management strategy aimed at maximising waste recovery while minimising environmental impact.

1.4.5. Responsible Disposal

Responsible disposal entails treating hazardous and final waste in accordance with environmental regulations, ensuring proper handling and disposal to minimise environmental harm. Within recycling initiatives, responsible disposal is a critical aspect of waste management practices, emphasising compliance with regulations to safeguard ecosystems and public health while promoting sustainable resource management.

1.4.6. Recycling

Aims to reintroduce waste materials back into the production cycle to reduce consumption of natural resources and minimise ultimate waste generation.

1.5. Natural Resource Utilisation and Management

This refers to how research infrastructure leverages natural resources like water, energy, materials, and land to conduct research activities and focuses on ensuring sustainable and responsible utilisation of natural resources within research infrastructure.

1.5.1. Raw Material/Resource Depletion

The gradual decrease in the availability of non-renewable natural resources due to intensive extraction and use.

- Consumption of raw materials for construction, equipment, and operation of research facilities.
- Generation of waste and pollution associated with resource extraction and utilisation.

Example of Measurement:

- Tracking raw material consumption by type and source.
- Evaluating the material footprint of the RI.

Combating Resource Depletion:

- Adopting eco-design and sustainable construction practices.
- Utilising sustainable and renewable materials where possible.
- Implementing waste recycling and recovery programs.

1.5.2. Water Usage / Water Consumption

The withdrawal and utilisation of freshwater for research needs, including drinking water, process water, and irrigation.

- **Cooling Systems:** Large-scale cooling systems, essential for maintaining optimal server temperature, are major water consumers. These include chilled water loops, cooling towers, and evaporative cooling systems.
- **Humidification:** Certain IT equipment may require humidity control to prevent static electricity buildup, leading to additional water use.
- Discharge of wastewater that can potentially pollute natural environments.

Measurement:

- Tracking water consumption by type of use.
- Installing smart water metres for real-time data collection.

Reducing Water Consumption:

- Implementing water-efficient technologies within research activities.
- Reusing wastewater for non-potable applications.
- Raising awareness among personnel about water conservation efforts.

1.5.3. Land Use

The occupation and transformation of land surfaces for research infrastructure needs, including buildings, facilities, and green spaces.

- Land artificialization and destruction of natural habitats.**
- Landscape fragmentation and potential loss of biodiversity.

Measurement:

- Monitoring land use by type (buildings, green spaces, etc.)
- Mapping of natural and sensitive areas within the RI's footprint.

Sustainable Land Management:

- Reducing the overall land footprint of the RI through innovative building designs or shared facilities.
- Restoring artificialized areas and promoting biodiversity within the infrastructure.

1.6. Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a systematic process aimed at assessing the potential effects of human activities on the environment. This category evaluates the environmental impact of activities and products, considering factors such as ecological toxicity, human health risks, and eutrophication. It addresses adverse effects on ecosystems, human health, and water quality, providing insights into the overall environmental sustainability of processes and products.

1.6.1. Ecotoxicity

This measure assesses the harmful effects of chemicals on living organisms and ecosystems. It examines how chemicals used in industrial processes or end products can impact biodiversity, the health of aquatic and terrestrial ecosystems, as well as populations of plant and animal species.

1.6.2. Human Toxicity

This dimension evaluates potential risks to human health associated with exposure to toxic substances present in the environment. This includes exposure to chemical contaminants in air, water, and soil, as well as short and long-term effects on human health, such as respiratory illnesses, cancers, and developmental disorders.

1.6.3. Eutrophication

This process refers to the excessive enrichment of nutrients, particularly phosphorus and nitrogen, in aquatic ecosystems. Eutrophication can result from runoff of agricultural fertilisers, urban or industrial wastewater, and can lead to excessive algae growth, the formation of dead zones devoid of oxygen, and disruption of aquatic ecosystems.

Energy consumption is the total amount of power used over a set period, typically measured in Watt-hours (Wh), which represents the integral of power consumption over time (e.g., one hour).

2. Prioritisation of Indicators

According to the Joint Research Centre (JRC) in the report "Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs)"[2]. The table below ranks the indicators from most to least prioritised (must, should, Nice To Have) using colour-coding (**red**, **yellow**, **green**).

Indicator	Classification
Energy consumption	Must Have
Energy efficiency	Must Have
Use of renewable energy	Must Have
Waste heat recovery	Must Have
Carbon Emissions and Greenhouse Gas	Must Have
Waste Sorting and Recycling	Must Have
Waste Reduction at Source	Should Have
Recycling	Should Have
Raw Material	Should Have
Water Usage	Should Have
Waste heat recovery	Nice To Have
Composting	Nice To Have
Energy from Waste	Nice To Have
Responsible Disposal	Nice To Have
Land Use	Nice To Have
Ecotoxicity	Nice To Have
Human Toxicity	Nice To Have

[2] *European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/093662, JRC136475.*

Eutrophication	Nice To Have

3. European and International Regulation, Best Practices and ISO Standards

3.1. European Code of Conduct for Data centre Energy management

This is the key and practical document produced annually by the European Commission (EC) and Joint Research Centre (JRC). We refer to the publication of 2024:

> European Commission, Joint Research Centre, Baldini, G., Cerutti, I. and Chountala, C., Identifying common indicators for measuring the environmental footprint of electronic communications networks (ECNs) for the provision of electronic communications services (ECSs), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/093662 , JRC136475.

The proposed Survey uses recommended structure in assessing energy and environment impact and recommended KPI to assess and monitor the whole complex data centre facilities and processes.

The document has the following structure:
3. Data Centre Utilisation, Management and Planning
4 IT Equipment and Services
5 Cooling
6 Data Centre Power Equipment
7 Other Data Centre Equipment
8 Data Centre Building

And section 9 Monitoring provides necessary advice on defining monitoring KPI
9.1 Energy Use and Environmental Performance Measurement
9.2 Energy Use and Environmental Data Collection and Performance Logging
9.3 Energy Use and Environmental Performance Reporting
9.4 IT Reporting

Table 9 from the document provides a list of recommended but mostly optional KPIs for data centre monitoring that can reviewed by digital RIs

Table 9. Energy Use and Environmental Performance Reporting

> Energy use and environmental (temperature and humidity) data needs to be regularly reported to be of use in managing the energy efficiency of the facility.

No	Name	Description	Expected	Value

9.3.1	Written Reportin g	Minimum reporting consists of periodic written reports on energy consumption and environmental ranges. All written reports and submissions should reference the Category being reported and ensure that the required method of data collection and calculation determined by the Standardised ISO KPIs from the *ISO/IEC 30134* series (or *EN 50600-4-X* equivalent), should be used in all reports, written or otherwise if reported. The Standardised KPIs include PUE, pPUE, REF, ITEESV, ITEUSV, ERF, CER, CUE, WUE. Note: Determining the averaged Data Centre Infrastructure Efficiency (DCiE) or PUE over the reporting period is already mandated by the Code of Conduct reporting requirements. This report may be produced by an automated system. Note: All DCiE and PUE calculations should be completed according to the guidelines set out by *EN 50600-4-2* which is equivalent to *ISO/IEC 30134-2*. *EN 50600-4-2* "Information technology — Data centre facilities and infrastructures — Part 4-2: Power Usage Effectiveness . Note: Different categories of PURE ranging from 0 to 3 representing increasing levels of reporting granularity.	Entire Data Centre	4

No	Name	Description	Expected	Value
9.3.2	Energy and environmental reporting console	An automated energy and environmental reporting console to allow M&E staff to monitor the energy use and efficiency of the facility provides enhanced capability. This supersedes the requirements for Written Reporting. See section 9.3.1 above with regard to correct method of calculation and the use of Standardised ISO/IEC KPIs or European equivalents if reported.	Optional	4
9.3.3	Integrated IT / M&E energy and environmental reporting console	An integrated energy and environmental reporting capability in the main IT reporting console allows integrated management of energy use and comparison of IT workload with energy use. Averaged, instantaneous and working ranges of Standardised ISO/IEC KPIs are reported and related to IT workload. This supersedes Written Reporting and Energy and environmental reporting console. This reporting may be enhanced by the integration of effective physical, logical asset and configuration data. See section 9.3.1 above with regard to correct method of calculation and the use of Standardised ISO/IEC KPIs or European equivalents if reported.	Optional	4
9.3.4	Achieved free cooling / economizer cooling hours	Require reporting of full free cooling, partial free cooling and full refrigerant and compressor based cooling hours throughout the year. The intent being to report the amount or time and energy spent running on mechanical refrigerant and compressor based cooling versus the use of free cooling in order to reduce the amount of time spent on mechanical cooling during the year. The site design, cooling system operational set-points and IT equipment environmental control ranges should allow the data centre to operate without refrigeration for a significant part of the year with no refrigeration for the IT cooling load as evaluated against a Typical Meteorological Year for the site. Note: This refers to mechanical compressors and heat pumps, any device which uses energy to	New build or retrofit	4

		raise the temperature of the rejected heat.		

No	Name	Description	Expected	Value
9.3.5	PUE and Partial PUE Reporting	Report Power Usage Effectiveness and partial PUE (PUE and pPUE) according to *EN 50600-4-2 or ISO/IEC 30134-2*. If partial PUE is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for PUE. This should be based on kW/h consumption and a consistent IT Load. Suggestions for come from EN 50600-5-1 (5.1.3.1)	Optional	4
9.3.6	REF Reporting	Report REF according to *EN 50600-4-3 or ISO/IEC 30134-3*. If REF is reported the Standardised KPI should be used.	Optional	4
9.3.7	ITEEsv Reportin g	Report IT Equipment Energy Efficiency for Servers (ITEEsv) according to *EN 50600-4-4 or ISO/IEC 30134-* *4*. If ITEEsv is reported the Standardised KPI should be used.	Optional	4
9.3.8	ITEUsv Reportin g	Report IT Equipment Utilisation for Servers (ITEUsv) according to *EN 50600-4-5 or ISO/IEC 30134-5*. If ITEUsv is reported the Standardised KPI should be used.	Optional	4
9.3.9	ERF Reporting	Report Energy Reuse Factor (ERF) according to *EN 50600-4-6 or ISO/IEC 30134-6*. If CER is reported the Standardised KPI should be used.	Optional	4
9.3.10	CER Reporting	Report Cooling Efficiency Ratio (CER) according to *EN 50600-4-7 or ISO/IEC 30134-7*. If CER is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for CER. This should be based on kW/h consumption and a consistent IT Load. Suggestions come from EN 50600-5-1 (8.13.1)	Optional	4

9.3.11	CUE Reporting	Report Carbon Usage Effectiveness (CUE) according to *ISO/IEC 30134-8*. If CUE is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for CuE. This should be based on kW/h consumption and a consistent IT Load.	Optional	4

No	Name	Description	Expected	Value
9.3.12	WUE Reporting	Report Water Usage Effectiveness (WUE) according to *ISO/IEC 30134-9*. If WUE is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for WUE. This should be based on kW/h consumption and a consistent IT Load.	Optional	4

Option to present information from Table 9 in the textual form.

9.3.1 Written Reporting
Minimum reporting consists of periodic written reports on energy consumption and environmental ranges. All written reports and submissions should reference the Category being reported and ensure that the required method of data collection and calculation determined by the Standardised ISO KPIs from the ISO/IEC 30134 series (or EN 50600-4-X equivalent), should be used in all reports, written or otherwise if reported.

The Standardised KPIs include PUE, pPUE, REF, ITEESV, ITEUSV, ERF, CER, CUE, WUE.

Note: Determining the averaged Data Centre Infrastructure Efficiency (DCiE) or PUE over the reporting period is already mandated by the Code of Conduct reporting requirements. This report may be produced by an automated system.

Note: All DCiE and PUE calculations should be completed according to the guidelines set out by EN 50600-4-2 which is equivalent to ISO/IEC 30134-2.

EN 50600-4-2 "Information Technology" Data centre facilities and infrastructures Part 4-2: Power Usage Effectiveness.

Note: Note: Different categories of PUE ranging from 0 to 3 representing increasing levels of reporting granularity.

Other recommended Monitoring items listed below (using numbers from Table 9)

9.3.5 PUE and Partial PUE Reporting
Report Power Usage Effectiveness and partial PUE (PUE and pPUE) according to EN 50600-4-2 or ISO/IEC 30134-2. If partial PUE is reported the Standardised KPI should be used.
Consider advocating the use of trending rather than hard targets for PUE. This should be based on kW/h consumption and a consistent IT Load. Suggestions for come from EN 50600-5-1 (5.1.3.1)
Optional

9.3.6 REF Reporting
Report REF according to EN 50600-4-3 or ISO/IEC 30134-3. If REF is reported the Standardised KPI should be used.
Optional

9.3.7 ITEEsv Reporting
Report IT Equipment Energy Efficiency for Servers (ITEEsv) according to EN 50600-4-4 or ISO/IEC 30134-4.If ITEEsv is reported the Standardised KPI should be used.
Optional

9.3.8 ITEUsv Reporting
Report IT Equipment Utilisation for Servers (ITEUsv) according to EN 50600-4-5 or ISO/IEC 30134-5. If ITEUsv is reported the Standardised KPI should be used.
Optional

9.3.9 ERF Reporting
Report Energy Reuse Factor (ERF) according to EN 50600-4-6 or ISO/IEC 30134-6. If CER is reported the Standardised KPI should be used.
Optional

9.3.10 CER Reporting
Report Cooling Efficiency Ratio (CER) according to EN 50600-4-7 or ISO/IEC 30134-7. If CER is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for CER. This should be based on kW/h consumption and a consistent IT Load. Suggestions come from EN 50600-5-1 (8.13.1)
Optional

9.3.11 CUE Reporting
Report Carbon Usage Effectiveness (CUE) according to ISO/IEC 30134-8. If CUE is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for CuE. This should be based on kW/h consumption and a consistent IT Load.
Optional

9.3.12 WUE Reporting
Report Water Usage Effectiveness (WUE) according to ISO/IEC 30134-9. If WUE is reported the Standardised KPI should be used. Consider advocating the use of trending rather than hard targets for WUE. This should be based on kW/h consumption and a consistent IT Load.
Optional

3.2. European developed standards on data centres design and operation EN 50600

European developed standards on data centres design and operation EN 50600 are actually focused on implementation of the international ISO 30134 standard series. It covers various aspects to ensure data centres are built and managed according to best practices for efficiency, safety, and reliability. Here are some of the key parameters and areas addressed by the ISO 50600 series:

1. Site Selection: Guidelines for choosing a location for a data centre, considering factors such as geographical risks, accessibility, and connectivity.
2. Building Design: Standards for the architectural and engineering design of the facility, focusing on sustainability, security, and efficiency.
3. Power Infrastructure: Specifications for electrical design that ensure uninterrupted power supply, including redundancy, distribution, and energy efficiency.
4. Cooling Systems: Guidelines for cooling infrastructure to manage the thermal environment effectively, which is critical for maintaining the operational integrity of the hardware.
5. Security Systems: Standards for physical and environmental security measures to protect data centre assets from unauthorised access and various threats.
6. Telecommunications Infrastructure: Criteria for the design and installation of telecommunications cabling and equipment.
7. Management and Operations: Best practices for the ongoing operation and maintenance of the data centre, including environmental monitoring, safety procedures, and operational processes.
8. Environmental Conditions: Parameters for controlling the internal environment, including temperature, humidity, and cleanliness.
9. **Energy Efficiency**: Guidelines to optimise energy use and promote sustainability, including the use of renewable energy sources and energy-efficient technologies.
10. Scalability and Modularity: Recommendations for designing data centres that can be easily scaled or modified to meet changing demands.

The following standards are currently published:

The ISO 50600 series encompasses several parts, each addressing different aspects of data centre requirements and management. Here's a breakdown of what each part generally covers:

ISO 50600-1: General Concepts

ISO 50600-2-x: Facility Requirements

ISO 50600-3-x: Operational Requirements

ISO 50600-4-x: Key Performance Indicators

- **ISO 50600-4-1: Overview and Concepts: Introduces key performance indicators (KPIs) for assessing and measuring data centre performance.**
- **ISO 50600-4-2: Power Usage Effectiveness (PUE) and Renewable Energy Factor (REF): Specifies KPIs for energy efficiency and sustainability.**

These standards help organisations design, manage, and operate data centres that meet high levels of efficiency, security, and reliability. Each part of the ISO 50600 series is structured to provide detailed guidance on specific aspects of data centre operations, ensuring comprehensive coverage of all critical areas.

50600-4-1 identifies Key Infrastructure Components and Functional Modules

Power Supply and Distribution:
Components: Uninterruptible Power Supplies (UPS), Power Distribution Units (PDUs), generators, transformers, and electrical panels.
KPIs: Total energy consumption, power distribution efficiency, and reliability of power supply.

Cooling Systems:

Components: Computer Room Air Conditioners (CRACs), chillers, cooling towers, air handlers, and liquid cooling systems.
KPIs: Energy consumption of cooling systems, cooling efficiency, temperature stability, and effectiveness in maintaining optimal operating conditions.

IT Equipment:
Components: Servers, storage devices, networking equipment (routers, switches).
KPIs: Energy usage by IT equipment, utilisation rates, processing power, storage capacity, and network bandwidth utilisation.

Environmental Control Systems:
Components: Humidity control systems, environmental monitoring systems, air quality systems.
KPIs: Energy used for environmental control, effectiveness in maintaining optimal conditions, and overall air quality.

Physical Infrastructure:
Components: Racks, cabling infrastructure, physical layout, and security systems.
KPIs: Space utilisation, security incident rates, ease of maintenance, and physical infrastructure efficiency.

Support Systems:
Components: Lighting, fire suppression systems, access control systems.
KPIs: Energy consumption of support systems, effectiveness of fire suppression, access control effectiveness, and lighting efficiency.

50600-4-2 identifies Specific Infrastructure Components for PUE Measurement
Utility Energy Meter:
Components: Metres to measure total energy consumption from the utility grid.
KPIs: Total energy usage of the data centre, forming the basis for the numerator in PUE calculations.

IT Equipment Energy Consumption:
Components: Energy metres specific to IT equipment, such as servers and storage.
KPIs: IT energy consumption, forming the denominator in PUE calculations.

Power Distribution Systems:
Components: Distribution boards, electrical panels, PDUs, UPS systems.
KPIs: Energy losses in power distribution, efficiency of power conversion, and overall power distribution efficiency.

Cooling Infrastructure:
Components: CRAC units, chillers, liquid cooling systems, cooling towers.
KPIs: Cooling energy consumption, efficiency metrics related to IT load, and overall cooling system efficiency.

Auxiliary Systems:
Components: Lighting, security systems, fire suppression systems.

KPIs: Energy consumption of auxiliary systems, contribution to total energy usage, and efficiency of auxiliary systems.
Practical Use for KPI and Performance Assessment

Data Collection and Monitoring:
Implementation: Deploy accurate energy metres and monitoring systems across all identified components to collect reliable data.
Purpose: Ensure precise measurement for calculating KPIs such as PUE and other efficiency metrics.

Performance Optimization:
Analysis: Use collected data to identify inefficiencies in power usage, cooling performance, and IT equipment utilisation.
Actions: Implement improvements like optimising airflow, upgrading to more efficient equipment, and enhancing power distribution systems.

Benchmarking:
Internal: Compare performance across different data centres within the same organisation to identify best practices and areas for improvement.
Industry: Benchmark against industry standards and best practices to identify gaps and opportunities for enhancement.

Reporting and Compliance:
Reporting: Provide transparent and standardised reports on energy efficiency and other KPIs to stakeholders.
Compliance: Ensure adherence to regulatory requirements and achieve certifications for energy efficiency and sustainability.

On the datacenter monitoring EN 50604-1 defines general KPIs used in datacenters and supporting infrastructure components identified.

EN 50600-4-2 focuses on Power Usage Effectiveness (PUE) as a key KPI for assessing the energy efficiency of data centres. The standard defines different categories of PUE measurements:

PUE Categories:
PUE1: Measured at the utility metre, representing the total energy consumed by the data centre.
PUE2: Measured at the data centre facility level, which excludes some non-IT energy uses.
PUE3: Measured at the IT equipment level, focusing solely on the energy used by IT equipment.

Calculation and Reporting:
Total Energy Consumption: Includes all energy sources used by the data centre.
IT Energy Consumption: Energy used by IT equipment such as servers, storage, and network devices.

Energy Efficiency Measures:

Energy Distribution Efficiency: Efficiency of power distribution systems like UPS and PDUs.
Cooling Efficiency: Efficiency of cooling systems in relation to IT energy consumption.

Auxiliary Systems:

Lighting Energy Consumption: Energy used by lighting systems within the data centre.
Security Systems Energy Consumption: Energy consumed by security and monitoring systems.

Practical Use
Data Collection: Implement monitoring systems to collect data for these KPIs, ensuring accurate and consistent measurement.
Performance Monitoring: Regularly analyse KPI data to identify areas for improvement and track progress over time.
Benchmarking: Compare KPIs against industry standards and best practices to identify gaps and opportunities.
Optimization: Use KPI data to optimise energy usage, improve cooling efficiency, and enhance overall operational effectiveness.

By utilising these KPIs, data centre operators can improve their energy efficiency, optimise resource usage, and ensure high performance and reliability of their digital infrastructure (https://www.en-standard.eu) (BSI Group) (Socomec APAC) (Dutch Data Centers).

3.3. International standards ISO 50001, ISO 50002, ISO 14002, ISO 30134

The group of international standards ISO 50001, ISO 50002, ISO 14002, ISO 30134 provides a basis for defining requirements for datacenter energy measurement, auditing environment impact assessment, measurement, and reduction. The following are the short summaries of the mentioned above standards.

ISO 50000 is a series of international standards focusing on energy management systems, intended to help organisations save energy, reduce costs, and improve energy performance. The core component of this series is ISO 50001, which provides a framework for establishing, implementing, maintaining, and improving an energy management system.

Here are the primary components and relevant standards in the ISO 50000 family:

- **ISO 50001: Energy Management Systems** - This standard specifies requirements for establishing, implementing, maintaining, and improving an energy management system. The goal is to enable an organisation to follow a systematic approach in achieving continual improvement of energy performance, including energy efficiency, use, and consumption.
- **ISO 50002: Energy Audits** - Specifies the requirements for conducting energy audits, which are a key component of an energy management system. It defines the processes and methodologies for performing audits. ISO 50002 categorises energy audits into three types:

- Type 1: Basic Energy Audit — focuses on brief analysis, simple paybacks without a detailed review of plant and utility data.
- Type 2: Detailed Energy Audit — involves detailed energy cost savings and project cost analyses based on detailed field data and discussions.
- Type 3: Precision Energy Audit — incorporates more detailed data collection and more rigorous evaluations of energy savings and costs, including monitoring and simulation.

ISO 14000 is a family of international standards related to environmental management that help organisations minimise how their operations negatively affect the environment, comply with applicable laws, regulations, and other environmentally oriented requirements, and continually improve in these areas.

Here are the primary components of the ISO 14000 series:

- **ISO 14001: Environmental Management Systems** - This is the core standard of the ISO 14000 series, providing a framework for organisations to develop an effective environmental management system (EMS). It offers a systematic approach for managing environmental responsibilities in a way that contributes to the environmental pillar of sustainability.
- **ISO 14004: Environmental Management Systems - General Guidelines on Implementation** - Provides additional guidance on how to set up, implement, maintain, and improve an environmental management system, supporting the application of ISO 14001.
- **ISO 14031: Environmental Management - Environmental Performance Evaluation - Guidelines** - Helps organisations evaluate their environmental performance using indicators.
- **ISO 14040 Series (ISO 14040 and ISO 14044): Environmental Management - Life Cycle Assessment** - Specifies the framework and principles for conducting life cycle assessments (LCAs) to evaluate the environmental impacts of a product, process, or system.

ISO/IEC 30134 Series defines datacenter Key Performance Indicators (KPIs) and metrics for data centre energy efficiency and performance. Examples include:

- ISO/IEC 30134-2: IT Equipment Energy Efficiency for Servers
- ISO/IEC 30134-3: IT Equipment Energy Efficiency for Storage
- ISO/IEC 30134-5: Data Centre Infrastructure Efficiency (DCiE)

As mentioned above European implementation of ISO 30134 series is defined in European EN 50600 series.

3.4. Technical publications and research on digital infrastructure research

Energy Efficiency: An Overview - Future Networks. (2019, May 8). GSMA. Retrieved April 3, 2024, from https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

Yan Dong, Michael Z. Hauschild. "Indicators for Environmental Sustainability. *Procedia CIRP* 61. (2017): 697-702.

How to Calculate and Measure Greenhouse Gas Emissions. (2023, July 10). Ecometrica. Retrieved April 3, 2024, from https://ecometrica.com/knowledge-bank/guides/how-to-calculate-measure-ghg-emissions-guide/

ATIS White Paper *Green G: The Path Toward Sustainable 6G [online]* https://nextgalliance.org/white_papers/green-g-the-path-towards-sustainable-6g/

ARCEP - Enquête annuelle "Pour un numérique soutenable" - édition 2024 (données 2022) - In French only - Annual survey "For a sustainable digital world" – 2024 edition (2022 data) [online] https://www.arcep.fr/u/c8tz-aa4a

The Shift Project - Digital https://theshiftproject.org/en/category/thematic/digital/

Annex C – ESFRI RM2026 checklist for dimension "Environmental considerations"

CHECKLIST FOR DIMENSION "ENVIRONMENTAL CONSIDERATIONS"

This checklist is intended to assist the formulation of answers on the dimension 'environmental considerations'. It provides the substantive environmental 'headline' issues for which ESFRI project proposals are invited to **examine whether they are relevant (hence to be addressed in an environmental strategy) or not, as the case may be**.

The elements are listed in relation to their appearance in the series of environmental (draft) European Sustainability Reporting Standards and their so-called 'disclosure requirements', namely: ESRS E1 (Climate change), ESRS E2 (Pollution), ESRS E3 (Water and marine resources), ESRS E4 (Biodiversity and Ecosystems) and ESRS E5 (Resource use and circular economy). References below to these disclosure requirements (and paragraph numbers therein) allow to find more detailed explanations there.[1]

A. Elements to consider in relation to Climate
(ref. ESRS E1 disclosure requirements E1-1, E1-2, E1-3, E1-4, E1-5, E1-6, E1-7, E1-8, E1-9)

	CHECKLIST OF POTENTIAL ISSUES under E1-1 Transition plan for climate change mitigation[2]	**Potentially relevant? (YES/NO)**
1	(17) Resilience in relation to climate change	
	CHECKLIST OF POTENTIAL ISSUES under E1-2 Policies related to climate change mitigation and adaptation	**Potentially relevant? (YES/NO)**
2	(22) Material impacts, risks and opportunities related to climate change mitigation and adaptation	
3	(23) Whether and how policies address the energy efficiency and renewable energy deployment	
	CHECKLIST OF POTENTIAL ISSUES under E1-3 Actions and resources in relation to climate change policies	**Potentially relevant? (YES/NO)**
4	(24) Climate change mitigation and adaptation actions and the resources allocated for their implementation	
5	(27b) (Scope for) achieving / expecting reductions in GHG emissions	
	CHECKLIST OF POTENTIAL ISSUES under E1-4 Targets related to climate change mitigation and adaptation	**Potentially relevant? (YES/NO)**
6	(31) Setting GHG emissions reduction targets to manage material climate-related impacts, risks and opportunities, for example, renewable energy deployment, energy efficiency, climate change adaptation, and physical or transition risk mitigation	
7	(32f) The expected decarbonisation levers and their overall quantitative contributions to achieve the GHG emission reduction targets	
	CHECKLIST OF POTENTIAL ISSUES under E1-5 Energy consumption and mix	**Potentially relevant? (YES/NO)**
8	(35a) Total energy consumption from non-renewable sources	
9	(35b) Total energy consumption from renewable sources	
	CHECKLIST OF POTENTIAL ISSUES under E1-6 Gross Scopes 1, 2, 3 and Total GHG emissions	**Potentially relevant? (YES/NO)**
10	(42d) Total GHG emissions to provide an overall understanding of the project's GHG emissions and whether they occur from its own operations or the value chain	

[1] The target audience of the ESRS standards are companies (economic operators) and their investors; for their use in this different (non-economic-) ESFRI roadmap context, it should be understood that there is no need to consider any issues in relation to 'production' or other measures of economic output, but purely with respect to any significance they may have in the Research Infrastructure life-cycle context.

[2] The context of climate change mitigation policy is most clearly that of the objective of achieving climate neutrality by 2050 and how this affects the use of fossil fuels. All sectors are 'decarbonising', and also need to consider any 'lock-in' of greenhouse gas emissions. From the disclosure requirement E1-1, this checklist only specifically retains the element of 'resilience'.

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	CHECKLIST OF POTENTIAL ISSUES under E1-9 Potential financial effects from material physical and transition risks and potential climate-related opportunities	**Potentially relevant? (YES/NO)**
11	(63b) the proportion of assets at material physical risk addressed by the climate change adaptation actions	
12	(64b) the proportion of assets at material transition risk addressed by the climate change mitigation actions	

B. Elements to consider in relation to **Pollution**
(ref. ESRS E2 disclosure requirements E2-1, E2-2, E2-3, E2-4, E2-5)

	CHECKLIST OF POTENTIAL ISSUES under E2-1 Policies related to pollution	**Potentially relevant? (YES/NO)**
13	14(a) Mitigating negative impacts related to pollution of air, water and soil including prevention and control	
14	14 (b) Minimising and substituting substances of concern and phasing out substances of very high concern	
15	14 (c) Prevention of incidents and emergency situations	
	CHECKLIST OF POTENTIAL ISSUES under E2-2 Actions and resources related to pollution	**Potentially relevant? (YES/NO)**
16	18(a) Avoiding pollution including any phase out of materials or compounds that have a material negative impact (prevention of pollution at source)	
17	18(b) Pollution reduction, including any phase-out of materials or compounds and by meeting enforcement requirements	
	CHECKLIST OF POTENTIAL ISSUES under E2-3 Targets related to pollution	**Potentially relevant? (YES/NO)**
18	22 Targets relating to the prevention and control:	
	(a) of air pollutants and respective specific loads	
	(b) of emissions to water and respective specific loads	
	(c) of pollution to soil and respective specific loads	
	(d) of substances of concern and substances of very high concern	
	CHECKLIST OF POTENTIAL ISSUES under E2-4 Pollution of air, water and soil	**Potentially relevant? (YES/NO)**
19	27(a) emissions of air pollutants	
	27(b) emissions to water	
	27(c) emissions of inorganic pollutants	
	27(d) emissions of ozone-depleting substances	
	27(e) microplastics generated or used	
	CHECKLIST OF POTENTIAL ISSUES under E2-5 Substances of concern and substances of very high concern	**Potentially relevant? (YES/NO)**
20	30. Production, use, distribution, … of substances of concern and substances of very high concern	

C. Elements to consider in relation to **Water and marine resources**
(Ref. ESRS E3 disclosure requirements E3-1; E3-3)

	CHECKLIST OF POTENTIAL ISSUES under E3-1 Policies related to water and marine resources	**Potentially relevant? (YES/NO)**
21	11(a) Water management including the use and sourcing of water and marine resources in own operations	
22	11(b) Product and service design in view of addressing water-related issues and the preservation of marine resources	
23	11(c) Commitment to reduce material water consumption in areas at water risk in its	

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	own operations and along the upstream and downstream value chain	
	CHECKLIST OF POTENTIAL ISSUES under E3-3 Targets related to water and marine resources	**Potentially relevant? (YES/NO)**
24	In case any of the E3-1 items were relevant ('YES'): 23. consideration of specific ecological thresholds and entity-specific allocations	

D. Elements to consider in relation to **Biodiversity and ecosystems**
(ref. ESRS E4 disclosure requirements E4-1, E4-2, E4-3, E4-5)

	CHECKLIST OF POTENTIAL ISSUES under E4-1 Transition plan on biodiversity and ecosystems[3]	**Potentially relevant? (YES/NO)**
25	22c) Whether or not it has sites located in or near biodiversity-sensitive areas and whether activities related to these sites negatively affect these areas …	
	22c … i) by leading to the deterioration of natural habitats and the habitats of species and to the disturbance of the species for which a protected area has been designated	
	22c … ii) necessary mitigation measures (…) on the conservation of natural habitats and of wild fauna and flora (in relation to implementation of nature protection legislation)	
26	22e) Whether it has identified material negative impacts with regards to land degradation, desertification or soil sealing	
	CHECKLIST OF POTENTIAL ISSUES under E4-2 Policies related to biodiversity and ecosystems	**Potentially relevant? (YES/NO)**
27	26e) Traceability of products, components and raw materials with significant actual or potential impacts on biodiversity and ecosystems along the value chain	
28	27a) Biodiversity and ecosystem protection policy covering operational sites owned, leased, managed in or near a protected area or a biodiversity-sensitive area outside protected areas	
29	27b) sustainable land / agriculture practices or policies	
30	27c) sustainable oceans / seas practices or policies	
31	27e) policies to address deforestation	
	CHECKLIST OF POTENTIAL ISSUES under E4-3 Actions and resources related to biodiversity and ecosystems	**Potentially relevant? (YES/NO)**
32	27a) Layer in the mitigation hierarchy a key action can be allocated to: avoidance, reduction and minimisation, restoration and rehabilitation	
33	27c) Incorporation of local and indigenous knowledge and nature- based solutions into biodiversity and ecosystems-related actions;	
	CHECKLIST OF POTENTIAL ISSUES under E4-5 Impact metrics related to biodiversity and ecosystems change	**Potentially relevant? (YES/NO)**
34	42a) The conversion over time (e.g., one or five years) of land cover (e.g., deforestationor mining)	
35	42b) Changes over time (e.g., one or five years) in the management of the ecosystem (e.g., through the intensification of agricultural management, or the application ofbetter management practices or forestry harvesting)	
36	42c) Changes in the spatial configuration of the landscape (e.g., fragmentation of habitats, changes in ecosystem connectivity)	
37	42d) Changes in ecosystem structural connectivity (e.g., habitat permeability based on physical features and arrangements of habitat patches)	
38	42e) Changes in ecosystem functional connectivity (e.g., how well genes, gametes, propagules or individuals move through land, freshwater and seascape)	

[3] The so-called 'triple planetary crisis' refers to the three main interlinked issues that humanity currently faces: climate change, pollution and biodiversity loss (UNFCC, 2022). The context of global biodiversity and ecosystems policy is formulated in the Kunming-Montreal Global Biodiversity Framework, with its clear targets, and the EU policy context that is adjusted to that Framework. From the disclosure requirement E4-1 this checklist only retains site-related elements.

E. Elements to consider in relation to **Resource use and circular economy**
(ref. ESRS E5 disclosure requirements E5-1, E5-2, E5-3, E5-5)

	CHECKLIST OF POTENTIAL ISSUES under E5-1 Policies related to resource use and circular economy	Potentially relevant? (YES/NO)
39	15(a) Transitioning away from extraction of virgin non-renewable resources	
40	15(b) Securing and contributing to the regenerative production of renewable resources and the regeneration of ecosystems they are part of	
	CHECKLIST OF POTENTIAL ISSUES under E5-2 Actions and resources related to resource use and circular economy	Potentially relevant? (YES/NO)
41	20(b) More detailed circular economy strategy throughout the value chain of the product: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture and Repurpose), Recycle	
	CHECKLIST OF POTENTIAL ISSUES under E5-3 Targets related to resource use and circular economy	Potentially relevant? (YES/NO)
42	25. Whether and how its targets relate to inflows and outflows, including waste and products and materials (including in production, use phase and at end of functional life)	
	CHECKLIST OF POTENTIAL ISSUES under E5-5 Resource outflows	Potentially relevant? (YES/NO)
43	35(b) Waste management strategy and the extent to which the project knows how its waste is managed	

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