GreenDIGIT

Greener Future Digital Research Infrastructures

Deliverable 10.2 Definition of the competences and skills for sustainability and environmental impact awareness and a set of training modules

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List of Abbreviations

Abbreviation	Description
API	Application Programming Interface
BoK	Body of Knowledge
CCS	Classification Computer Science
CF-DS	Data Science Competence Framework
DS-BoK	Data Science Body of Knowledge
DSPP	Data Science Professional Profiles
EDSF	EDISON Data Science Framework
eIRG	Infrastructure Research Group
EOSC	European Open Science Cloud
ERA	European Research Area
ESCO	European Skills, Competences, Occupations
ESD	Education for Sustainable Development (UNESCO)
ESFRI	European Strategy Forum on Research Infrastructures
FAIR	Findable, Accessible, Interoperable, Reusable
EGC	European Green Competence
GCF	Green Competence Framework
ICT	Information and Communication Technologies
KA	Knowledge Area
KU	Knowledge Unit
LU	Learning Unit
NLP	Natural Language Processing
RAB	Role and Activity Based
RDA	Research Data Alliance
RDE/IDE	Research/Integrated Development Environment (RDE/IDE)
RI	Research Infrastructure
SADF	Sustainable Architecture Design Principles
SDG	Sustainable Development Goal
SME	Small and Medium-sized Enterprises
SLICES	Scientific LargeScale Infrastructure for Computing/Communication Experimental Studies
SoBigData	The Research Infrastructure for Big Data and Social Mining
UN	United Nations
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
WP	Work Package

Executive Summary

Environmental sustainability and energy efficiency in digital research infrastructures (RIs) require specialized competences and skills to support the design, development, and operation of sustainable digital services, applications, and infrastructures, and beyond this need, to raise awareness among general researchers. This deliverable presents the initial results from **Task 10.4 – Training curricula development based on required skills for users, developers, and managers**. It provides an **overview and analysis of existing competence frameworks** related to sustainability, identifies gaps in technical competences for RI sustainability, and outlines training modules to address these needs.

While existing **Green Competence Frameworks** focus on general sustainability awareness and behavioural aspects, they lack the necessary technical skills for the sustainable development and operation of modern digital infrastructures. The **GreenDIGIT project** aims to bridge this gap by defining the necessary **technical and engineering competences** required for sustainability in RIs. These competences align with the **Reference Architecture for Sustainability** and **Sustainable Architecture Design Principles** developed in GreenDIGIT's **WP4 and WP5**, ensuring the best practices in system and software engineering are integrated into RI operations.

This deliverable defines an **initial set of training modules and curricula topics** tailored to different RI stakeholders, including **researchers, developers, operators, managers, and general users**. The training will be delivered through **GreenDIGIT summer schools, researcher and developer events, and RI-focused courses**. The topics also cover the effective use of digital tools and technologies developed within the project.

The work in WP10 and Task 10.4 was conducted in close collaboration with other work packages, particularly those focused on **sustainability policies (WP3, WP8) and architectural development (WP4, WP5)**. The report includes a reference to sustainability-related policies and regulations, an analysis of the **current university programs covering sustainability elements**, and an overview of **job market demands for green competences**, utilizing the **EDISON Data Science Framework (EDSF) methodology**.

The deliverable is structured as follows:

- **Chapter 2** reviews sustainability-related policies, competence frameworks, and related studies.
- **Chapter 3** defines green and sustainability-related competences, incorporating the GreenDIGIT **architecture framework and Sustainable Architecture Design Principles** for defining **technical competences in sustainability**.
- **Chapter 4** examines existing university programs with sustainability components.
- **Chapter 5** presents the **proposed training modules and learning units**, designed for diverse RI professional (developers, operators, management) and user groups.

By establishing a **structured approach to sustainability-related competences and training**, this deliverable contributes to enabling digital RIs to achieve sustainable and energy-efficient operation, in alignment with **ESFRI Roadmap 2026 environmental sustainability policy goals**.

1 Introduction

Environmental sustainability and energy efficiency of digital infrastructures and related services and user/researcher focused applications (wide and consistent implementation of sustainable technologies in RIs design and operation) requires necessary (certain profile of) competences and skills to develop scientific/research applications and RI based research services and tools. This should also be supported by necessary system and applications engineering knowledge.

This deliverable reports on the initial work done in Task 10.4 Training curricula development based on required skills for users, developers and managers that included an overview and analysis of existing competence frameworks defining sustainability related competences, what was followed by providing suggestions on how these competences need to be reflected in training and education curricula.

The deliverable provides a summary of the overview and analysis of existing recommendations and studies related to the definition of Environmental Sustainability and Energy Efficiency competences which are commonly referred to as Green Competences. Existing Green Competence Frameworks are focused on the general competences and intended understanding (and general attitude) of how to behave/act to achieve the intended sustainability goals. However, existing green/sustainability competence frameworks do not address the necessary technical competences for the technical development and operation of modern and future digital infrastructures and services.

The GreenDIGIT project intends to develop necessary architecture and infrastructure elements and services to ensure environmentally sustainable operation of the future digital Research Infrastructures (RI) and ensure support of the new ESFRI policy on the environmental sustainability of RIs as this is explained in the ESFRI Roadmap 2026 Public Guide [1][2]. The necessary sustainability-related competences and supporting professional training are recognised as important enabling factors in achieving the environmental sustainability goals. For digital RIs and data-driven research, this includes both adopting existing green competence frameworks and defining more technically focused competences and supporting education and training materials to support sustainability and energy efficiency aware practical development and operation of the RIs and infrastructure services and research applications for different user/researcher groups.

The technical and engineering competences definition is based on Reference Architecture for Sustainability (which is part of WP4 and WP5 development) and the proposed Sustainable Architecture Design Principles that provide a basis for well-architected infrastructure and research applications design, development and operation by incorporating the best practices in system and software engineering.

The defined competences and knowledge are linked to the organisational roles and related activities/functions in RI operation and management (both research, technical and management) for achieving a sustainable operation and minimised environmental impact.

This deliverable defines an initial set of training modules and curricula topics to address required competences and provides guidelines on how the training programs can be composed for different target groups of trainees/users, including researchers, infrastructure researchers and services developers, operators, managers, and general users. Core training modules will be developed as part of this task by the end of M18. Some of the courses will be delivered at different researcher and developer events, in particular the summer schools co-organised by the GreenDIGIT project in cooperation with partner RIs and other projects. The training topics will also include training on the effective use of digital technologies and tools developed in the project.

WP10 and Task 10.4 acted in tight cooperation with all other WPs to get an understanding of and contribution to defining the necessary competences and training modules. To demonstrate this, this report includes a short summary of the GreenDIGIT architecture development in WP4 and WP5 and a reference to sustainability related policies and regulations which analysis is done in WP3 and WP8.

The deliverable is structured in the following way: Chapter 2 provides an overview and analysis of the sustainability-related policies and competence frameworks. It also includes references to related studies. This provides important background information for developing sustainability- (or green-) related competences in the following chapters. Chapter 3 is focused on defining necessary green/sustainability-related competences, using the EDISON Data Science Framework (EDSF) methodology that the authors have used in a few previous projects to define different competences and curricula modules. In this report, the EDSF methodology was used to analyse the job market for demanded green competences. The chapter also introduces the GreenDIGIT architecture framework for sustainability and Sustainable Architecture Design Principles that together provide input for defining a set of necessary technical competences for designing, implementing and operating RIs in a sustainable way. Chapter 4 provides an overview and analysis of the existing university programs focused on or containing the sustainability elements. Chapter 5 provides a set of the proposed training modules, also defined as Learning Units, for different groups of users and developers and operators in Research Infrastructures. The conclusion chapter provides a summary of the presented information and suggestions for future developments.

2 Importance of Competences Related to Environmental Sustainability – Overview of existing frameworks and trends

This chapter starts with a summary of the UNESCO Education for Sustainable Development program and recommended competences to support SDG17. This is followed by the analysis of the European Green Competence Framework (GreenComp) that provides a general definition of the competences important for all workers to possess to responsibly and effectively implement (concisely work) existing recommendations related to environmental sustainability. The chapter also includes a brief overview of other relevant European competence frameworks, in particular digital competences for researchers and educators, that can be beneficially extended with the environmental sustainability dimension.

2.1 UN Sustainable Development Goals (SDG17) and Defined Competences

2.1.1 UN Sustainable Development Goals

The sustainability of our planet and life is recognised internationally as one of the priorities to address in all human activities with the general goal to preserve our planet's environment and ensure renewable use of resources, and ensure in this way sustainable development of our civilization. The **17 Sustainable Development Goals (SDGs)**, as they are universally defined and referenced in the context of "Partnerships for the Goals" (SDG 17) [3][4], are listed below. These goals collectively form the 2030 Agenda for Sustainable Development. See Table 1 for brief SDG17 definition.

Table 1. UN Sustainable Development Goals (SDG17)

Goal 1: No Poverty End poverty in all its forms everywhere. **SDG02: Zero Hunger** End hunger, achieve food security and improved nutrition, and promote sustainable agriculture. **SDG03: Good Health and Well-being** Ensure healthy lives and promote well-being for all at all ages. **(**) SDG04: Quality Education** Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. **SDG05: Gender Equality** Achieve gender equality and empower all women and girls. **SDG06: Clean Water and Sanitation** Ensure availability and sustainable management of water and sanitation for all.	**SDG10: Reduced Inequality** Reduce inequality within and among countries. **(*) SDG11: Sustainable Cities and Communities** Make cities and human settlements inclusive, safe, resilient, and sustainable. **SDG12: Responsible Consumption and Production** Ensure sustainable consumption and production patterns. **(*) SDG13: Climate Action** Take urgent action to combat climate change and its impacts. **SDG14: Life Below Water** Conserve and sustainably use the oceans, seas, and marine resources for sustainable development. **SDG15: Life on Land** Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and

(*) SDG07: Affordable and Clean Energy Ensure access to affordable, reliable, sustainable, and modern energy for all. **SDG08: Decent Work and Economic Growth** Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. **(**) SDG09: Industry, Innovation, and Infrastructure** Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.	reverse land degradation and halt biodiversity loss. **SDG16: Peace, Justice, and Strong Institutions** Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels. **(*) SDG17: Partnerships for the Goals** Strengthen the means of implementation and revitalize the global partnership for sustainable development.

SDG04 Quality Education and SDG09 Industry, Innovation, and Infrastructure are marked with (**) as the most relevant to the research community and the project. They actually define the focus of the different project development activities: technical, policy, education, and the primary focus of dissemination. Other SDGs: SDG07 Affordable and Clean Energy, SDG11 Sustainable Cities and Communities, SDG13 Climate Actions, SDG17 Partnership for the Goals, - define the project's outreach and community engagement activities based on understanding the importance of the RI to support research and education for the full Sustainable Development Goals implementation.

2.1.2 UNESCO Education for Sustainable Development (ESD) Program and SDG17 Related Competences

The competences that are aligned with the UNESCO ESD (Education for Sustainable Development) [5][6][7] are aimed to transform education into a platform for empowering individuals to contribute to a more sustainable future through collective and collaborative efforts. The following are the identified competences and education areas to be addressed by education to facilitate the adoption of Sustainable Development Goals and practices (ordered in the order of relevance to RI activities and actors and roles).

1. **Practical Skills for Sustainable Action**:
   - Provide training on practical tools and methodologies for implementing sustainable practices and initiatives.
   - Encourage project-based and action-oriented learning to address real-world sustainability challenges.
2. **Sustainability Literacy**:
   - Understand key sustainability principles such as resource efficiency, ecological balance, and resilience.
   - Develop skills for assessing and improving environmental performance.
3. **Technological Proficiency**:
   - Use digital tools, modelling, and technologies to address sustainability challenges.
   - Evaluate the environmental impact of emerging technologies.
4. **System and Critical Thinking and Holistic Approaches**:
   - Teach learners to analyse complex systems and interconnections between economic, environmental, and social factors.

- Highlight the integration of SDGs into education policies, curricula, and institutional governance.

5. **Interdisciplinary Collaboration Skills and Partnership Building**:
   - Develop skills for fostering collaboration among diverse stakeholders (e.g., public, private, and civil society sectors).
   - Promote inter-sectoral partnerships and cooperative frameworks to address sustainability challenges.
6. **Knowledge of Governance and Policy Development**:
   - Equip learners with an understanding of governance structures and policy-making processes related to sustainable development.
   - Emphasize the importance of aligning institutional and community actions with global sustainable development goals.
7. **Ethical Principles and Communication Skills Decision-Making**:
   - Understand values of fairness, inclusivity, and responsibility to guide ethical decision-making in sustainability efforts.
   - Promote the ability to engage and mobilize local and global communities for collaborative actions.

These competencies and educational areas align with the overarching goals of ESD (Education for Sustainable Development) to transform education and supported professional training into a platform for empowering individuals to contribute to a more just and sustainable future through collective and collaborative efforts.

As one of the projects to define sustainability related skills and link them to the organisation and functioning typical societal ecosystem, UNESCO developed a framework with the key features of learning cities (as a prospective model for future sustainably developing cities) at the centre of which there are six pillars or "building blocks" which support sustainable development. The article [8] focuses on the third of these pillars, "effective learning for and in the workplace"[1]. The author analyses a number of conditions to address this aspect in the context of "green restructuring" which is targeted towards facilitating the sustainable development of learning cities. The author argues that, at the conceptual level, an understanding of the nature of "green skills" (what they are) and the reasons for "green skills gaps" (why they exist) are essential for the processes of effective learning and strategy planning in sustainable city development.

This deliverable approaches the "green" competences and skills from the point of view of the research community and European Research Area (ERA) ecosystem, including Research Infrastructure and necessary services, typical scientific research activities, roles and actors, and taking into account the Research Infrastructures lifecycle. The project will take into account the ESD recommended competences and education areas explained above.

2.2 European Green competences framework

The European Green Competence Framework (GreenComp), is a comprehensive structure developed by the European Commission's Joint Research Centre (2022) [9]. This framework identifies and

[1] This paper is also available online https://www.researchgate.net/profile/Margarita-Pavlova-2/publication/325109665_Fostering_inclusive_sustainable_economic_growth_and_green_skills_development_in_learning_cities_through_partnerships/links/601e5209a6fdcc37a806480e/Fostering-inclusive-sustainable-economic-growth-and-green-skills-development-in-learning-cities-through-partnerships.pdf

categorizes four key competence areas. Each area contains three distinct competences. The framework is integral to advancing sustainable development. The majority of competences stated in this framework are considered soft skills upon examining the definition from Cimatti (2016) [10].

A noticeable feature of this framework is the non-hierarchical approach to the competences. This means that although the competences are structured with ascending numbers, all the competences are equally important and that learners are encouraged to develop all of them. The groups in GreenComp are divided as follows:

EGC01: Embodying sustainability values
Embodying sustainability values encourages us to reflect on and challenge our own personal values and world-views in terms of unsustainability, and sustainability values and world-views. This area advocates equity and justice for current and future generations, while supporting the view that humans are a part of nature.

EGC02: Embracing complexity in sustainability
Embracing complexity in sustainability is about empowering learners with systemic and critical thinking, and encouraging them to reflect on how to better assess information and challenge unsustainability. Framing challenges as sustainability problems, will help us learn about the scale of a situation while identifying everyone involved.

EGC03: Envisioning sustainable futures
Envisioning sustainability futures enables learners to visualise alternative future scenarios and identify actions to achieve a sustainable future. It is essential that learners acquire the competence of 'adaptability' while coping with uncertainty about the futures and trade-offs in sustainability. Applying creative and trans-disciplinary approaches to our way of thinking can foster a circular society and encourage learners to use their imagination when thinking about the future.

EGC04: Acting for sustainability
Acting for sustainability encourages learners to take action at individual and collective levels to shape a sustainable future, to the extent possible. It also invites learners to demand action from those responsible to make change happen.

Table 2 provides the list of green competences by groups and suggested links to related activities in the RI lifecycle stages (the details of the RI lifecycle definition and corresponding roles and activities are provided in Chapter 3).

Table 2. European GreenComp competence groups and link to RI Lifecycle activities

1. Embodying sustainability values 1.1 Valuing sustainability 1.2 Supporting fairness 1.3 Promoting nature	Provides a basis for general environmental sustainability education and attitude and aptitude focused training.
2. Embracing complexity in sustainability 2.1 Systems thinking 2.2 Critical thinking 2.3 Problem framing	System and design thinking, supported by critical and analytic thinking is a basis for all stages related to RI and research applications design, development and operation.
3. Envisioning sustainable futures 3.1 Futures literacy 3.2 Adaptability	Sustainability literacy, adaptability and exploratory thinking are important for both researchers and RI operators who need to align their research process

3.3 Exploratory thinking	and RI maintenance with the sustainability goals and necessary practices.
4. Acting for sustainability 4.1 Political agency 4.2 Collective action 4.3 Individual initiative	This group of competences and skills is important to develop the conscious, active position by researchers, developers, operators, and managers.

The GreenComp framework and competences provide a basis for defining the necessary attitude and aptitude skills[2] that the researchers and all actors in RI lifecycle stages need to possess to ensure effective and environmentally sustainable RI operation. These kinds of skills are not domain-specific but need to be aligned with the specific scientific or technology domain when included in education curricula. In professional education, they can be provided (implemented) as focused interactive tutorials or workshops.

2.3 Other European Competence Frameworks Related to Research and Education

The European Skills Agenda [11] includes a wide spectrum of activities to strengthen sustainable European competitiveness by addressing European needs for digital skills that include multiple skill areas, such as general digital skills, and specific areas related to competences and skills for researchers and educators. In this section, we provide a short reference to all three skill areas that are related to our community and to sustainability aspects of the future digital RIs where the competences, skills and knowledge are defining factors.

2.3.1 The European Competence Framework for Researchers

The European Competence Frameworks for Researchers [12] defines the seven competence groups: (1) Managing research, (2) Making an Impact, (3) Self-management, (4) Cognitive abilities, (5) Work with others, (6) Managing research tools, (7) Doing research. A detailed description of this competence group is provided in Appendix A and can be useful information for more specific sustainability related competences development and profiling for researchers.

For this deliverable and the current stage of Task 10.4 development, we can identify the following competences which can/should be supported by (or reflected in) general training curricula and tutorials in GreenDIGIT:

(1) Research compliance with and adoption of the general sustainability approaches is important and will become evaluation criteria, in particular, according to ESFRI Roadmap 2026 Guidelines [13].

(7) The GreenDIGIT outcome and multiple dissemination (publications) and outreach documents provide a framework for increasing impact with clearly defined target areas and groups, including facilitation of the policy development and implementation.

[2] Aptitude refers to the ability, talent, or competency to perform a specific task or job. Attitude is defined by one's belief, mentality, and drive to achieve a goal. This type of skills is often referred to as 21st Century Skills or Workplace Skills. In other models, they are referred to as horizontal skills required for all activities and workers.

(2) and (5) Making an impact by employing the Shared Responsibility Model for Sustainability (SRM4S) proposed and actively promoted by the GreenDIGIT project, and further related development by the project.

2.3.2 The European Framework for the Digital Competences of Educators

The European Framework for the Digital Competence of Educators (DigCompEdu) (2017) [14] defined six competence areas that educators need to possess to effectively guide the learners in mastering the digital competences (which are defined by EU DigComp and discussed in the next section):

Area 1: Professional Engagement
Area 2: Digital Resources
Area 3: Teaching and Learning
Area 4: Assessment
Area 5: Empowering Learners
Area 6: Facilitating Learners' Digital Competence

Analysis of the detailed DigCompEdu competences definition (refer to Appendix A) makes it beneficial to include elements of green competences in all areas of DigCompEdu. Recommendations to extend DigCompEdu can be provided for educational and training organisations and activities.

2.3.3 The Digital Competences and Data Literacy

In the context of digital transformation and growing AI-based automation, all professional profiles should possess sufficient levels of digital competences and skills to operate successfully in Industry 4.0. The EC study and report on "Digital Competence Framework for Citizens" (DigComp), initially published in 2018 and updated for version DigComp 2.2 in 2022 [15], provides good advice for addressing both digital skills and data skills in professional workplace training and vocational education. An important part of digital competences is understanding the role of data and processes related to data handling in modern applications, social media, industrial processes, research, and specifically how data are used in AI based decision making and control and how important it is to have a common information model for efficient energy efficiency optimisation and management. Special training and skills development must include data processing and management issues.

It is important to mention that the Digital Europe Program includes a special focus on Digital Skills for Small and Medium-sized Enterprises (SME) [16] that can be an important activity domain for promoting environmental sustainability aspects for Éuropean Digital SME's.

2.4 Existing Studies to Define Green Competences and Skills

The paper [17] is a valuable collection of studied literature (citing 66 publications primarily focusing on the economic, social and environmental aspects) and provides interesting insight into what aspects of green competences can be taken into account. The following dimensions are defined for green competences: awareness, knowledge, attitude, skills, abilities, and behaviour, where green behaviour should be adopted by both organisations/corporations and users (or citizens). However, the paper doesn't demonstrate a sufficient practical methodology to move from literature or job market analysis to formal competences definition and further move to defining necessary knowledge and learning modules.

The *Generic green skills* [18] defined by UNESCO Educational Centre for Technical and Vocational Education and Training [19] include general knowledge, skills, attitudes and values that are necessary for contributing to sustainable social, economic and environmental development in any job. Green skills are defined as skills needed to reduce environmental impacts and support economic restructuring with the purpose of attaining cleaner, more climate resilient and efficient economies that preserve environmental sustainability and provide decent work conditions. The development of generic green skills is important for the greening of all industries, as they enable a person to develop a green mindset and adopt generic operational practices that minimise environmental impacts.

References to studies and reviews focused on the sustainability competences and aspects in the university curricula are discussed in Chapter 4.

3 Defining Green Competence Framework for European Research Area

This section defines green and sustainability-related competences, incorporating the GreenDIGIT **architecture framework and Sustainable Architecture Design Principles** for defining **technical competences in sustainability.**

3.1 Methodology: EDISON Data Science Framework (EDSF)

This section introduces the EDISON Data Science Framework (EDSF) as a methodology for defining green competences as new emerging competences demanded by different economy sectors, and which are important for modern digital science. EDSF is a product of the EU funded project EDISON[3] (2015-2017) and currently maintained by the EDSF community and coordinated by the University of Amsterdam. The EDISON Data Science Framework is published in two books covering the general EDSF definition [20] and its application to the Big Data Infrastructure Technologies for Data Analytics and Data Management [21][22].

EDSF methodology was used to develop the Data Stewardship Competence Framework in the FAIRsFAIR project[4], digital skills for the maritime industry in the MATES project[5], and currently used to define Artificial Intelligence competences combining academic Body of Knowledge definition and job market demand [23].

The EDSF methodology provides a basis for job market analysis to define key demanded competences and skills, identify necessary knowledge topics and important curricula components based on analysis of the scientific domain classification (such as Association for Computing Machinery (ACM)/IEEE Classification Computer Science (CCS2012) [24]) and analysis of known and advanced curricula.

3.1.1 Structure and Components of the EDISON Data Science Framework

The EDISON Data Science Framework provides the basis for the definition of the data science profession and enables the definition of the other components related to data science education, training, organizational role definition and skills management, as well as professional certification.

Figure 1 illustrates the main components of the EDISON Data Science Framework and their interrelations that provide the conceptual basis for the development of the data science profession:

- Data Science Competence Framework (CF-DS) that includes the definition of competences, skills, attitudes, and linked knowledge topics
- Data Science Body of Knowledge (DS-BoK) that provides a structured definition of knowledge groups and topics for Data Science
- Data Science Model Curriculum (MC-DS) that includes definition of Learning Units (LU) and Learning Outcomes (LO)
- Data Science Professional Profiles and Occupations Taxonomy (DSPP) that defines the whole family of Data Science related professions

[3] https://edisoncommunity.github.io/EDSF/
[4] https://www.fairsfair.eu/
[5] https://projectmates.eu/

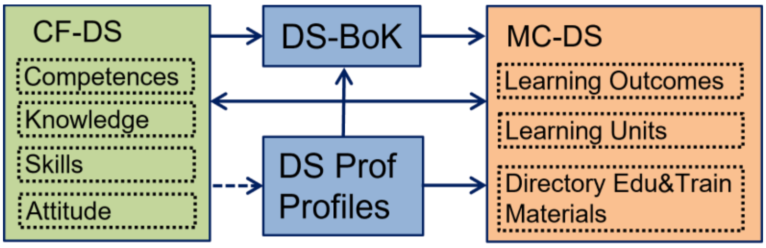

Figure 1. EDISON Data Science Framework components.

The EDSF specification (current version Release 4) can be found on the EDSF Community website https://edisoncommunity.github.io/EDSF/ and GitHub repository https://github.com/EDISONcommunity/EDSF/wiki/EDSFhome

The Competences Framework for Data Science (CF-DS) provides the overall basis for the whole EDSF. The core CF-DS includes common competences required for the successful work of data scientists in different work environments in industry and in research, and throughout the whole career path. The future CF-DS development may include coverage of the domain-specific competences and skills and will involve domain and subject matter experts.

The following core CF-DS competence and skills groups are identified (refer to CF-DS specification [25] for details):

- Data Science Analytics (including Statistical Analysis, Machine Learning, Data Mining, Business Analytics, and others) (DSDA)
- Data Science Engineering (including Software and Applications Engineering, Big Data Infrastructure and Tools, Data Warehousing) (DSENG)
- Domain Knowledge and Expertise (DSDK, Subject/Scientific domain related)
- Data Management and Governance (including data stewardship, curation, and preservation) (DSDM)
- Research Methods and Project Management (DSRMP)

The first two competence groups DSDA and DSENG are the core Data Science competences, which need to be complemented with the third group DSDK of domain related competences and knowledge for efficient Data Science applications. DSDM and DSRMP represent necessary competences in Research Data Management and Research Process Management, which are important for the efficient work of modern researchers.

In total, CF-DS includes 30 enumerated competences, 6 competences for each of the competence groups. The Data Science competences must be supported by the knowledge that are defined primarily by education and training, and skills that are defined by work experience correspondingly. The CF-DS defines two types of skills (refer to CF-DS [25] for the full definition of the identified knowledge and skills groups):

- Skills Type A, which are built based on practising major competences acquired based on education and training; depend on years of working as a Data Scientist or related roles,
- Skills Type B that are related to a wide range of practical computational skills, including using programming languages, development environment, and cloud based platforms.

The Data Science Body of Knowledge (DS-BoK) [26] defines the knowledge areas for building data science curricula that are required to support identified data science competences. DS-BoK is organized by knowledge area groups (KAGs) that correspond to the CF-DS competence groups. Each KAG is composed of knowledge areas (KAs). Each KA is composed of a number of knowledge units (KUs), which are currently the lowest component of the DS-BoK. DS-BoK incorporates best practices in computer science and domain-specific bodies of knowledge and includes KAs and KUs defined, where possible, based on the classification of computer science components taken from other bodies of knowledge and proposes new KAs/KUs to incorporate new technologies used in data science and their recent developments.

The DS-BoK is based on ACM/IEEE Classification Computer Science (CCS2012) [24] and incorporates best practices in defining domain specific BoKs. It provides a reference to related existing BoKs and includes proposed new KA to incorporate new technologies and scientific subjects required for consistent Data Science education and training.

The Model Curriculum for Data Science (MC-DS) [27] is built based on CF-DS and DS-BoK, where learning outcomes (LOs) are defined based on CF-DS competences and learning units (LUs) are mapped to knowledge units in DS-BoK. Three mastery, or proficiency, levels are defined for each learning outcome to allow for flexible curricula development and profiling for different data science professional profiles. The proposed learning outcomes are enumerated to have a direct mapping to the enumerated competences in CF-DS.

The Data Science Professional Profiles (DSPP) [28] defines a number of Data Science professional profiles in accordance with existing classifications, such as European standards ESCO [29] or EN 16234-1 “e-Competence Framework” [30]. The DSPP includes important parts of the competences relevance (scores) to each defined profile on a scale from 0 to 9 (from low to high) that can be used defining targeted education and training and building an effective career path. The DSPP definition provides an important instrument to define effective organizational structures and roles related to data science positions (e.g., building data science teams) and can also be used for building individual career paths and corresponding competences and skills transferability between organizations and sectors.

The current EDSF Release 4 is the result of cooperation and contribution by the wide community of academicians, researchers, and practitioners that are practically involved in data science and data analytics education and training, competences and skills management in organizations, and standardization in the area of competences, skills, occupations, and digital technologies.

3.1.2 EDSF Methodology for Competences Definition and Articulation

The EDSF methodology was developed and used for defining the initial set of Data Science competences for the newly emerging profession of the Data Scientist. There were no available formal and well-structured definitions of the Data Science competences but there was a strong market demand for new professionals with multiple job advertisements that described the expectations of companies and different categories of employer. The situation with green competences is different in a sense that we now have the EU GreenComp framework that can provide an initial definition or a starting point for job market analysis and competences definition improvement. This was done during the preparation stage of the project to better define the scope of activities and competences to be addressed in the development of training materials and curricula elements related to environmental sustainability and/or generally green competences.

The full EDISON/EDSF methodology used for the initial definition of Data Science competences and necessary data preparation is explained in Appendix B, with its use for green competences analysis.

It is important to describe a typical job vacancy structure that contains the following information that can be mapped to different components of a competence definition (such as competence, skills, knowledge, education, proficiency level):

- Job/position name, sometimes provided with the description of organisational roles and relations;
- Functions/responsibilities and abilities which can be mapped to competences, if competences are not explicitly defined (job vacancies usually use the term 'skills' instead of 'competences);')
- Skills and experiences, also including experience with tools and programming languages that all can be directly mapped to skills;
- Required knowledge or expected familiarity with named technologies or theories. This can be mapped to knowledge topics;
- Education, certification and proficiency level – can be mapped to a proficiency level that indicates mastering a certain level of a specific competence; but this information is rarely specified in the typical job vacancy.

Referring to the job vacancy structure, it is important to clarify the relations between competences, skills and knowledge, as illustrated in Figure 2 and used in the EDSF (which itself was adopted from the European e-Competences Framework (e-CF) and the corresponding standard EN 16234-1: 2019):

- **Competence** is a demonstrated ability to apply knowledge, skills and attitudes to achieve observable results.
- Competence includes/is supported by the **knowledge** that is obtained from education or (self-) training and by **skills** that are acquired as a result of practical experience.
- Professional profiles suggest necessary competences, skills and knowledge and ensure the ability to perform organisational functions.

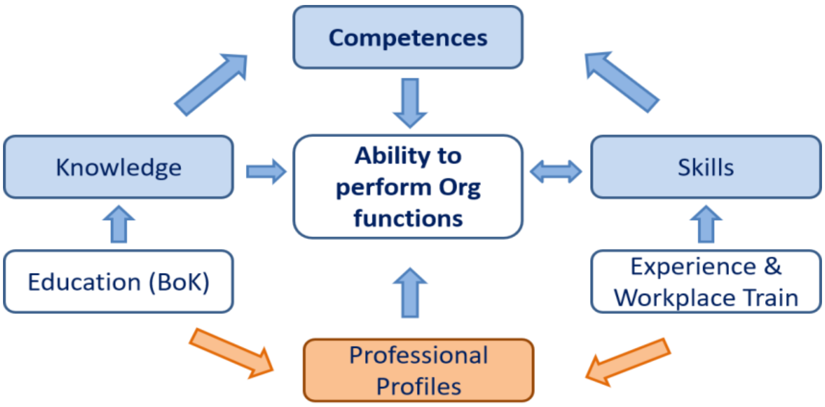

Figure 2. Relation between competences, skills and knowledge.

3.1.3 Job Market Analysis for Sustainability Related Competences

The job market analysis already started in the preparational stage of the GreenDIGIT project (beginning 2024) to identify the relevance of green competences defined in the EU GreenComp to the job market demand.

Job market data were collected from job advertisements on popular job search and employment portals indeed.com, LinkedIn Jobs and IEEE Jobs portals, where indeed.com provided the largest number of advertised vacancies with generally defined green or environmental sustainability-related competencies and positions. The collected data were used to extract information on competences, skills and knowledge demanded from prospective candidates to support the organisational green policies and practices. The following sections explain what approach was used for the analysis of vacancies and how the extracted information was mapped to the structure of the competences definition.

This section provides a summary of the job market analysis and observation that needs to be taken into account when defining the scope of necessary green competences. This can also be used to monitor or revise market demand for green competences in the future.

The results of assessing some selected job vacancies are illustrated in the diagrams below. The similarity score for each competence is visualized in a radar chart. The highest similarity score is mapped to one, to highlight nuances in the scores. The normalized similarity scores are then stored in a data frame which allows to have a good visualization in a radar chart. In addition, the highest similarity score is shown, in order to give some extra context to the graph. The radar charts are visualized in Figure 3 and Figure 4.

Figure 3.Similarity between GreenComp and selected vacancies (using GreenComp full paragraph)

Figure 4. Similarity between GreenComp and selected vacancies (using controlled vocabularies for individual competences)

The similarity score between vacancies and the full paragraphs of the GreenComp Framework paragraphs are visualized. In order to understand the visualizations, some details need to be considered. Since the similarity scores are normalized to 1, the relative difference in similarity scores is amplified. That is why in all radar charts, the competence with the highest similarity score is shown after the vacancy title. This highest score is mapped to 1.0. Since the highest similarity scores vary between 0.07 and 0.16, these visualizations are not decisive. To increase the similarity scores, the RAB-approach was used to create a controlled vocabulary for individual competences that are defined in the form of Role-Action-Based (see Appendix B, section B.2).

It is important to notice that the highest similarity score, where the normalized score is mapped to 1.0, is originally scoring between 0.2 and 0.26. The highest scoring competence over all vacancies is GCF_01 “Valuing Sustainability”. Another higher scoring competence is GCF_04 “System Thinking”. In all vacancies, most competences show some similarity, all around the same factor .5 of the highest scoring similarity score.

The general outcome of the market analysis showed that sustainability related competences are demanded in different sectors of the economy and industry but the definition of green competences needed to be improved (1) to make the definition of the competencies actionable and easily profiled for different roles in the organisational and business activities, (2) to provide clear recommendations for defining necessary curricula elements and training and education topics.

3.2 General Green Competences Extended from European Green Competence Framework

This section provides suggestions on how to improve the GreenComp definition. The outcome of the job market analysis contributed to a better definition of the general EU GreenComp, this was discussed during the EDULEARN2024 Conference [31].

Design and system thinking skills will allow to address energy efficiency and environmental sustainability aspects in RI technical design and operation, to avoid the researchers, developers and operators to focus on their limited set of functions and goals.

Table 3 introduces Green Competences enumeration using the prefix GCF – Green Competence Framework and assigning group and competence numbers and preserving the order of competences defined in GreenComp. Similar approach will be used for the enumeration of Learning Units or Modules and referring to the proposed tutorials.

Table 3. Extended GreenComp Competences Enumeration

Competence groups and individual competences	Suggested use for education and training curricula definition and practical use in RI/organisation operation
GCF1. Embodying sustainability values GCF1.01 Valuing sustainability GCF1.02 Supporting fairness GCF1.03 (*) Promoting nature and environment	Provide a basis for the general environmental sustainability education and attitude and aptitude focused training. • Can provide a basis for interactive or project based education and training. • In academic curricula, this can be part of general skills training.
GCF2. Embracing complexity in sustainability GCF2.01 Systems thinking GCF2.02 Critical thinking GCF2.03 Problem framing GCF2.04 (**) Understanding interconnection between Environmental, Social, Governance and Technical dimensions	System and design thinking, supported by critical and analytical thinking, is the basis for all stages related to RI and research applications design, development and operation. • To be enhanced with the Infrastructure, System and Scientific Applications Engineering elements • Sustainability focused system and design thinking to be added to education and training
GCF3. Envisioning sustainable futures GCF3.01 Futures literacy GCF3.02 (*) Adaptability and continuous development/evolution GCF3.03 Exploratory thinking	Sustainability literacy, adaptability and exploratory thinking are important for the operational stage of RI, where RI evolution and improvement are necessary due to continuous technology and research focus change.

	• Important component of training for RI technical and management operational staff, also research project management
GCF4. Acting for sustainability GCF4.01 (*) Political agency and advocacy GCF4.02 Collective action GCF4.03 Individual initiative GCF4.04 (**) Recognising Shared Responsibility in sustainability GCF4.05 (**)Defining and acting according to a roadmap	This group of competences and skills is important to develop a conscious, active position by researchers, developers, operators, and managers. • Can be part of the general training on introduction to sustainability aspects, policies and activities.

(*) Competences marked with this are modified (**) Competences marked with this are added

The initial work with the analysis of the GreenComp as described above allowed us to define some possible improvements to the current version of the GreenComp published in 2022. Contact has been established with the JRC team developed GreenComp to discuss possible updates based on the complex of identified additional general, technology and RI operation related competences, what can be considered as the GreenDIGIT contribution.

3.3 Technical Competences related to Infrastructure, Systems and Applications development and operation for Energy Efficiency and Environmental Sustainability

This section discusses the necessary technical competences to ensure the design, development, implementation and operation of the future digital RIs in energy efficient and environmentally sustainable way.

The technical and engineering competences group is based on the defined in the GreenDIGIT project Reference Architecture for Sustainability (which is part of WP4 and WP5 development) and proposes Sustainable Architecture Design Principles that provide a basis for defining necessary competences and knowledge for professional systems and infrastructure engineering design incorporating best practices in these domains.

The defined competences are connected with the general and domain specific competences required for modern data driven (and future generative AI assisted) research processes. This includes the identification of the main organisational roles/functions in RI operation and management (both research, technical and management) and consequently required competences and skills for operating and using RI resources in a sustainable and minimised environmental impact way.

3.3.1 Architecture and Operational Aspects of RI and necessary competences, skills, professional knowledge

Architecture definition, together with roles and actors, provide a basis for defining necessary competences and skills. The core architecture concept of the GreenDIGIT Reference Architecture for Sustainability (RA4S) is the Shared Responsibility Model for Sustainability (SRM4S) that has been developed in WP4 and discussed at multiple project meetings and conferences: Joint session between GreenDIGIT and EGI2024 Conference [32], ICRI2024 Conference [33], and PREDICT2024 [34].

The major concept of the SRM4S is the definition of the areas of responsibility of the RI providers and operators who are offering services to different categories of customers and customers and/or researchers that use the RI offered services and facilities to run their research and specific scientific workflow instances. The SRM4S defines the main RI components and overlay research project environment elements, on the technical side, and the main actors involved in the digital RI operation and research fulfilment, on the management side. Figure 5 illustrates the SRM4S in full detail to provide an understanding of the main functional components of the digital RI ecosystem, involving the provider side and the user/research side. This also provides a basis for understanding and defining what functions belong to different actors and what technical competences are required.

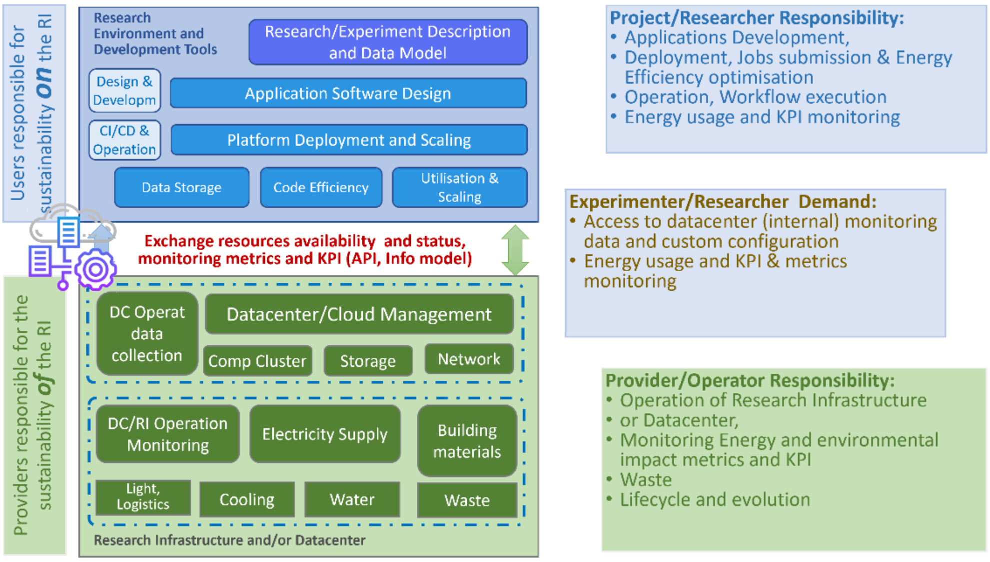

Figure 5. GreenDIGIT Shared Responsibility Model and Actor Groups

The figure also shows the three main groups of actors with their responsibilities and activities linked to RI operation and use (it is assembled in the Table 4):

Table 4. SRM4S actor groups and corresponding responsibilities and actions

Actor groups	Responsibilities and activities
User group – Uses RI services and available resources to run their scientific workflow • Researcher/ Scientific User • Project/Group user	**Project/Researcher Responsibility:** • Applications Development, • Deployment, Jobs submission & Energy Efficiency optimization • Operation, Workflow execution • Energy usage and KPI monitoring
Researcher/Developer of RI services – Requires access to data centre and RI services, facilities, monitoring and metrics • Large scale experimenter • Developer of new infrastructure services	**Experimenter/Researcher Demand:** • Access to data centre (internal) monitoring data and custom configuration • Energy usage and KPI & metrics monitoring
Operator group – Manages, monitors and maintains RI/data centre services and facilities	**Provider/Operator Responsibility:**

• RI (overlay) operator • Data centre operator • Facility owner	• Operation of Research Infrastructure or Data centre, • Monitoring Energy and environmental impact metrics and KPI • Waste management • Lifecycle and evolution

The formal definition of the necessary competences for different users and providers will be finished after GreenDIGIT Reference Architecture definition and reported in deliverable D4.2 in M15. At this stage, the presented analysis provided sufficient information for defining the initial set of training modules that will be defined in the next chapter.

The next section describes other technical, operational and management aspects in defining sustainability related competences in RI operation – the RI Lifecycle Model.

3.3.2 RI Lifecycle Model and Organisational Roles as a basis for the definition of related competence profiles

Figure 6 Illustrates the RI Lifecycle Model (RILM) that includes the following stages that have their specific activities and involve specific actors: (1) Concept development, (2) Design, (3) Preparation, development, (4) Implementation (Deployments and pre-operation), (5) Operation and Evolution, and finally, (6) Termination. The figure also shows the necessary link and required compliance with the standards and regulations, which also require knowledge of these standards and regulations by involved development and operational teams. Environmentally sustainable RI operation requires continuous monitoring and energy and environmental impact information what in turn requires multiple competences and knowledge. Table 5 provides a summary of the RI lifecycle stages and involved actors and activities which can provide input for defining the required competences and technical knowledge, and further definition of the required training modules.

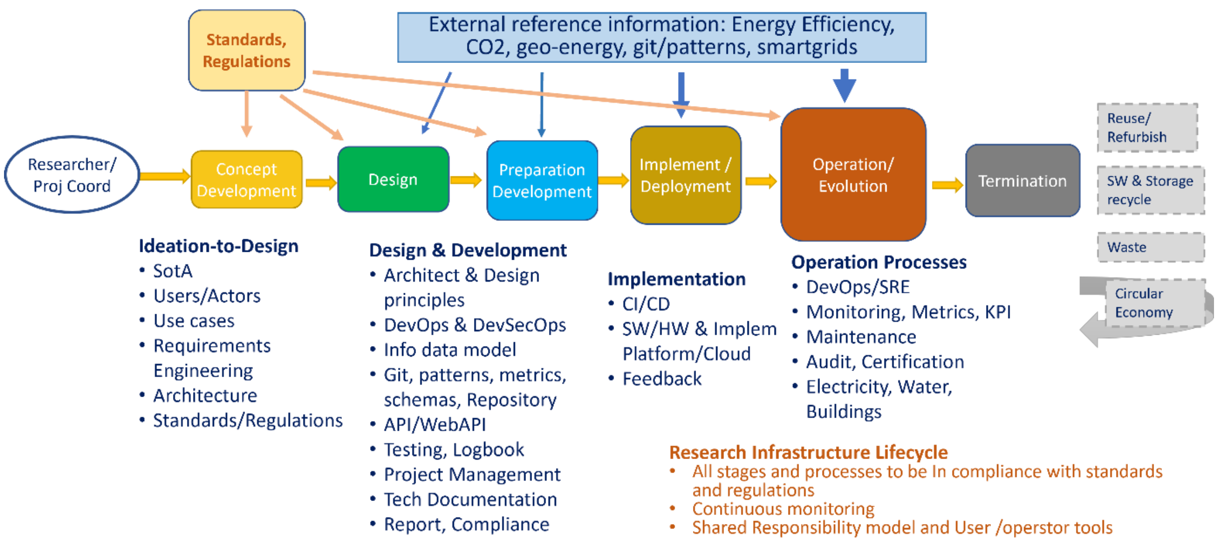

Figure 6. Research Infrastructure Lifecycle Model Identified activities

Table 5. RI Lifecycle stages, related actors and activities

RI Lifecycle Stage	Involved Actors	Activities
RI Concept development	Researchers (target RI users) Infrastructure and System Engineering team (professional, experienced)	**Concept development** (Ideation- for-Design) • SotA analysis • Users/Actors • Use cases analysis • Requirements Engineering • Architecture • Standards/Regulations analysis
Design and Development (preparation)	Researchers (consulting of domain related research facilities) Infrastructure and System Engineering team (professional, experienced) Application and service developers Project management	**Design & Development** • Architecture & Design principles • DevOps & DevSecOps • Info data model • Git, patterns, metrics, schemas, Repository • API/WebAPI • Testing, Logbook • Project Management • Tech Documentation • Reporting, Compliance
Implementation, Deployment (pre-operation)	Researchers (for pre-op testing) Infrastructure and System Engineering team Project management	**Implementation** • CI/CD • SW/HW & Implement Platform/Cloud • Feedback
Operation	RI Management (including staffing and financial aspects) Operation team (Potentially, sustainability officer)	**Operation Processes** • DevOps/SRE • Monitoring, Metrics, KPI • Maintenance • Audit, Certification • Electricity, Water, Buildings
Termination	Management Operator team	**Termination procedure** • Termination/Decommission plan and procedure, including recycle and circular economy procedures • Waste utilisation • Data archiving or migrating, secure storage recycling

The information presented in Table 5 is based on the summarised authors' and partners' experience and will provide a basis for further definition of the required competences and knowledge from/for different actors and roles during the RI lifecycle.

The next section provides a summary of the required technical competences and knowledge (system, infrastructure and applications engineering) for successful fulfilment of the main stages up to RI operation.

3.3.3 Sustainable Architecture Design Principles

Sustainable Architecture Design Principles (SADP) are proposed as a result of the project partners' experience with different infrastructure and applications development projects. This is also confirmed by teaching several master courses for Software Engineering and Big Data Infrastructure courses where SADP have been used for course project development. Architecture is a key element of sustainable/durable project development. Architecture provides a blueprint for systems and applications development and should ensure staged development and future sustainable system evolution.

The authors identified the Sustainable Architecture Design principles (SADP) as a necessary competence for designing, implementing and operating modern digital infrastructures, that is based on the authors' experience with projects and curricula development. The SADP and recommended competences have been presented at a few conferences throughout 2023-2024 [35][36].

SADP provides recommendations and guidance for the evolutional approach in designing and implementing complex infrastructure projects. SADP has been presented at a few conferences and discussions, which allowed to provide a better definition and more consistent with the RI/systems design for long-term and environmental sustainability by ensuring that the system design doesn't require continuous re-design and hardware software replacement what causes an electronic waste impact.

The complexity of modern systems and applications requires knowledge and competences in multiple technology and computer domains. The sustainable architecture intends to achieve lowering infrastructure or service resources, energy and waste along the whole service or infrastructure lifecycle, including concept, design, development, implementation/deployment, operation and termination/decommissioning that also includes supply chain, upgrade, replacement.

The following principles are derived from the existing architecture frameworks for the main structural and infrastructure components comprising modern digital and data infrastructures such as Internet architecture (in particular TCP/IP architecture), Telecom OSI model and related ITU-T standards, TeleManagement Forum, related ISO and IEEE standards, 5G/6G related standards, and others. At least two major cloud providers recently published their "Well architected" cloud services design recommendations (refer to AWS Well Architected framework [37] and Microsoft Azure Well architected framework [38]). The proposed recommendations are also supported by the research community's experience from different research and development projects as well as university teaching and professional training.

General architecture design principles

- Layered architecture design for services and mechanisms, including inter-layer interfaces, including cross-layer services and mechanisms definition that are typically defined as service planes, for example, management plane, security plane, data management plane.
- Multi-tier services and infrastructure design, including combined multi-layer and multi-tier systems that may use or apply different architectural and layered solutions.
- Other architecture styles may be used for specific tasks and applications: web-queue-worker, event-driven, Big Data, data-centric and data-driven as an alternative to compute-centric.
- Application Programming Interfaces (API) for composable services that must be supported by consistent information and data model (and fully qualified API metadata and namespaces definition).

Service architecture related

- Service Oriented Architecture (SOA) and Microservices Architecture (MSA) that is supported with the different VM and container solutions and/or platforms.
- Cloud powered, cloud based and cloud native design principles that require knowledge of the modern cloud architecture and cloud platform, both Open Source and public clouds (at least Amazon Web Services, Microsoft Azure, and Google Cloud Platform). This also includes such powerful cloud based mechanism as Virtual Private Cloud (VPC) that provide VPN based secure environment for multi-tenant customer applications.
- Service lifecycle management model that should include all necessary services to support lifecycle stages in the context of specific services. This also includes service composition and orchestration for service deployment and operation.
- Services and data management continuity in IoT/sensor networks, edge, cloud, data-driven applications that also include 5G/6G Radio Access Network (RAN), edge and cloud convergence.

Data infrastructure and related services

- Big Data computation models and supporting platforms, distributed and highly scalable systems, in particular, Hadoop and Spark ecosystems and NoSQL databases.
- Data management infrastructure and services that should cover two domains: services data (mostly related to the management plane) and research or business data produced as a result of scientific research or business operation.
- Data management continuity in two dimensions: infrastructure elements and scientific workflow stages, ensuring consistent data documenting and lineage (can also be referred to as FAIR data principle widely adopted by the research community) [39].

Security and compliance design principles

- Security architecture and security services lifecycle management which are well defined by numerous standards and supported by the major infrastructure development frameworks; also security services have their own multi-layer architecture (can also be referred to as security plane), their integration with the main infrastructure services, including data infrastructure) is realized via API calls and consistent definitions of the security roles, access control policies and credentials and secrets management.
- Compliance frameworks that define requirements and recommendations for secure services and infrastructure design and operation. Cloud Security Alliance (CSA) and Compliance Assessment Initiative Questionnaire (CAIQ) provide the best overview of all important standards and regulations to ensure systems security and compliance, and data protection.

Project Management and DevOps

- DevOps and SRE (Site Reliability Engineering) practices applied to system and services engineering and operation. This should also include continuous monitoring and optimisation on multiple user centric and business-centric SLI/KPI (Service Level/Key Performance Indicators).
- DevSecOps that extended the DevOps model and practices by addressing security aspects during the whole system/services lifecycle, intending to address "Security by Design" concept (however not yet fully developed)
- General compliance with the project management principles, models and procedures applied to infrastructure, services, and data handling and analytics.

A wider scope of architecture design principles can be found in standards and recommendations related to enterprise architecture design, such as the NIST Enterprise Architecture Model (EAM) [40], which divides the architecture description into domains, layers, views, and offers perspectives models. A similar approach is used in TOGAF architecture definition [41]. This provides a framework and a tool for the systemic design approach and decisions on the different components of the system. This also paves the way for making long-term decisions about design requirements, sustainability, and system or service evolution. Guidelines are provided in both documents/frameworks.

SADP understanding and related knowledge, competences and skills are not fixed but need to evolve with researcher or developer professional development as well as technology evolution.

The described SADP are implemented and tested in master courses on Big Data Infrastructure Technologies and DevOps and Software Engineering taught by authors.

The presented SADP provides a basis for defining necessary competences and knowledge, but it is not possible to ensure this level of training via workplace tutorials. However, the necessary level of competences and skills can be acquired by a team member as a result of successful projects fulfilment with several years of career and practical experience.

4 Overview Existing Curricula Addressing Green Competences and Skills

This chapter provides a brief overview and analysis of known academic programs and curricula that are focused on different aspects of sustainability for Information and Communication Technologies (ICT) and digital infrastructures, including such infrastructure components as data centres, networks, clouds, edge, IoT.

4.1 Green competences in academic curricula

4.1.1 Green Competences in University Curricula

The project identified a number of university programs and courses at the partner universities UTH, TUM, UvA, and a few other universities in Europe, that include energy efficiency and/or environmental sustainability topics in ICT disciplines. Information about the collected courses is available in Appendix C. Here, we present some common identified practices and approaches.

Most of the courses are related to the important technology domains in Computer Science, Computer Networks, 5G/6G technologies, Systems Engineering and general digital technologies. The sustainability aspects are addressed in dedicated lectures that introduce aspects of energy-efficient systems, network and infrastructure design, and a set of practices and labs that help students to understand and practically experiment with obtaining energy consumption/efficiency metrics, using corresponding CPU level and system tools, and consequently experiment with energy efficiency optimisation. Important methodology in addressing sustainability-related competencies and developing sustainability-related attitudes and system and design thinking in introducing sustainability-related criteria in the course that uses the project-based education model. Students are required to address sustainability-related aspects in their project design, use/select related architecture design patterns and are advised to sustainability related topic for their projects.

This practice is actively used, in particular by the authors at the University of Amsterdam, in close cooperation with the Vrije Universiteit (NL) as briefly discussed in the next section.

TUM publishes a sustainability report which covers all aspects of the university [42]. It offers 49 study programs that have sustainability at the core plus 69 that have a strong connection to sustainability. The TUM Institute for LifeLong Learning targets a very broad audience, from mid-level to senior and executive level. It features sustainability aspects in the digital world as one of its key topics.

4.1.2 Sustainability and Energy Efficiency Topics in University Curricula in The Netherlands

According to the Universiteit van Amsterdam Research and Education roadmap, modules on sustainability are in increasing demand. This is in line with the Dutch educational landscape [43] where the need to prepare youth for the future labour market has been identified as a main driver of organising future education. The 2024 report [44] finds that educational institutions scored on average 62% of the available 55 points , with three universities scoring full points (TU Delft, Vrije Universiteit and Zody Hogeschool). The three institutions have in common that their organisational policy mandates that sustainability ***has*** to be covered by all educational programmes. Other aspects considered by the report are: minors or electives where sustainability is integrated; integration of frameworks such as SDGs or the Donut economy in courses and teaching activities; support and training facilities for teaching staff with the goal to increase sustainability knowledge and thus integrate it in the curriculum.

In terms of best practices, the main highlight is the Comenius Leadership-project 'You Have a Part to Play', where student-teacher pairs work bottom-up in an action research method to identify intrinsic sustainability concerns for their course. There is a pair for each course at the university and the academic hospital associated with the university.

Dutch academic and research communities demonstrate a strong commitment to address sustainability related topics in Computer Science, Information Systems, Artificial Intelligence and Software Engineering, where the University of Amsterdam, in line with the Vrije Universiteit introduces sustainability related elements in Bachelor and Master courses. This is clearly demonstrated in a few relevant entries in the table of courses in Appendix C that are referenced in the previous section.

4.2 Needs for sustainability elements in curricula for System and Software Engineering

The system and software engineering provides a basis for designing, implementing and operating energy efficient and sustainable Research infrastructures in both dimensions: long term sustainability (durability) and environmental sustainability.

The in previous sections presented overview and analysis of existing competence frameworks, covering the general green competences and those required for building environmentally sustainable and energy efficient research infrastructures and research facilities, provide a sufficient basis for defining a set of Learning Units that will create a foundation for defining the Model Curriculum for teaching and training on the sustainability related competences and skills required for future green/environmentally sustainable RIs and (greening) research in general.

There are few studies that focused on investigating the need for sustainability competences in Computer Science and Software Engineering and how they are reflected in the current university curricula.

A paper [45] presented an interesting study on the understanding of the sustainability competencies and skills in software engineering from the industry point of view, based on interviews with companies from a few European countries during 2023. The study revealed the industry understanding of the growing need for sustainability skills in software engineering for developing efficient software products and services operations. However, the curricula topics or expected learning outcomes were not defined.

A Systematic Literature Review on sustainability in Computing Education [46] collected valuable information that allowed to define a set of recognised (or expected) sustainability competences that include: system thinking, multi-perspective thinking, transformation mindset, judgement, creativity, communication, ecological approach, meta-learning, research methods, critical thinking. However, the paper identified limited set of topics being taught, covering only climate change, sustainable development concepts and SDG, ethical and social goods.

A recently published paper [47] provided an extensive study to identify how to integrate sustainability into Software Engineering education. The paper collected information from interviews on overall interest in sustainability, sustainability goals, sustainability related competences and skills. The interviewed individuals acknowledged the importance of soft skills and technical competencies, but companies experience difficulties in hiring the right candidate with suitable sustainability-related skills. The companies admitted the need for good communication skills and knowledge about sustainability metrics. It was also admitted the need for sustainability related training courses and consultants on sustainability. The training should provide general information and raise awareness about basic sustainability concepts that should provide a basis for sustainability aware/focused system thinking, sufficient knowledge about sustainability metrics and KPI, and have a clear methodology for integrating sustainability related aspects into the Software Engineering curriculum and practice. It is recommended to have sustainability elements in project based courses and team work in general.

The primary focus for the GreenDIGIT project is to develop necessary training courses to design, develop and support the operation of future RIs in an environmentally sustainable way. The suggested set of training modules presented in the next chapter will provide the necessary input and experience for implementing sustainability aspects in academic curricula.

5 Proposed Training Topics and Learning Units for Research and Academic Community

This chapter presents a list of the proposed training topics that are derived from the analysis and identification of the required competences and skills for different organisational roles involved in the digital RI design, implementation and operation, actually covering the whole RI lifecycle. At this stage of the project and Task 10.4 development, we are focusing primarily on the operational stage that involves RI users, who are primarily researchers, and operators that include management and technical operational personnel and need to cover different RI and Research facilities.

5.1 Important competences, knowledge skills to manage environmental sustainability aspects

The following competences, knowledge and skills are required from the RI operator to successfully operate research infrastructure facilities and services and support their user and customer community:

- Knowledge and understanding of **SDG17 goals in general and specific goals related to digital RI operation and effective use for research, education and knowledge sharing SDG04 Quality Education, and SDG09 Industry, Innovation and Infrastructure**.
    - From the beginning of their introduction, SDG provided a common framework and actually shaped all development, initiatives and technologies related to sustainability in different technology and society domains.
    - For domain-specific research, other SDGs may be important to know.
- General knowledge of **environmental sustainability policies and regulations** that may include international policies and treaties, European regulations, national or local where the RI is established and operates its facilities and services.
- Knowledge of the **environmental sustainability related standards** is important for RI operation, but also important for RI design and development to ensure RI compliance with standards, regulations and corresponding certification.
- Identified **environmental sustainability and energy efficiency aspects related to the RI operation** stage
    - However, environmental aspects for other RI lifecycle stages must also be identified and analysed.
- **Shared Responsibility Model for Sustainability proposed by GreenDIGIT** that provides a good instrument for defining and understanding the interaction of all involved parties and stakeholders in the RI operation and use. This includes the following aspects important for understanding by different roles and categories of users.
    - **RI/data centre energy and environmental impact related metrics and KPI** that should be supported by necessary reporting and user dashboard. Mapping between energy related metrics and CO_2/Carbon footprint (or embedded footprint) is also important.
    - For technical development and infrastructure focused research, knowledge and understanding of **API and corresponding information model (and metadata)** are beneficial.
- Understanding the **Research Infrastructure Lifecycle Model (RILM)** is important for researchers and RI developers that may also include aspects related to personal and institutional energy-saving policies.

- Knowledge and use/mastering of the **environmental impact assessment tools and Research/Integrated Development Environment (RDE/IDE)** is important, primarily for researchers
  - Such tools and RDE/IDE must be provided and supported by RI providers

The listed above knowledge topics must be included in the general training curricula definition and supported by training and tutorials to be provided for different categories of users, developers and technical operational staff.

5.2 Proposed set of Learning Units as a basis for the initial set of tutorials

The presented below Learning Units (LU) can be used to develop tutorials for the different stakeholder groups that include researchers, research project developers and implementers, RI services and applications developers, RI operators, and RI managers (as decision makers).

5.2.1 Tutorial topics for general researchers (RI users) and experimental researchers on RI (GRIU)

The tutorial topics listed below are defined as Learning Units of an estimated 30-60 minutes duration that can be composed in the targeted tutorial or workshop. All GRIU LUs will be provided with supporting reference information and learning materials. This group of tutorial topics/LUs is targeted to be developed in the project and delivered as project training activities or part of jointly organised events (tutorials, workshops, summer/winter schools).

- LU-GRIU01: SDG17 overview and existing initiatives and programs related to SDG04 Quality Education, and SDG09 Industry, Innovation and Infrastructure (20-45 minutes)
- LU-GRIU02: Environmental sustainability policies and regulations: international policies and treaties, European regulations, national or local (30-60 minutes)
- LU-GRIU03: Environmental sustainability related standards: ISO, EN (European), ITU-T. Related regulations for compliance and existing certification programs.
- LU-GRIU04: Shared Responsibility Model for Sustainability (proposed by GreenDIGIT) as an instrument for defining and realising the interaction between all involved parties and stakeholders in the RI operation and use (30-45 minutes)
- LU-GRIU05: Research Infrastructure Lifecycle Model (RILM) as an important framework for planning institutional and personal energy-saving policies (30-60 minutes)
- LU-GRIU06: Research Development Environment, in particular, JupyterNotebook based for research workflow development and execution. Practice with available selected tools such as EGI Notebook or SoBigData JupyterLab (60-90 minutes)
- LU-GRIU07: RI/data centre energy and environmental impact related metrics and KPI. Assessing and optimising energy consumption by the scientific workflow based on available energy related metrics and CO_2/Carbon footprint (or embedded footprint) (60-90 minutes, with practical exercises)

It is also important to mention that all modules will include a brief overview of the GreenDIGIT project structure, project activities, and related technical and policy publications, in particular, this may include the outcome of the RI landscape analysis, Shared Responsibility Model, and other information materials.

5.2.2 Tutorials for research application developers (Software and System Engineering for Sustainability - SSES)

This group of tutorials is relevant and important for the infrastructure researchers and RI services developers but has quite a high technical level and necessary pre-requisites. Development and teaching of such tutorials will require the involvement of technical experts and experienced developers, who may not be sufficiently available in the project. Development of this group of tutorials will be considered as possible future development and in cooperation with other projects and partners.

Due to the technical complexity of the topics listed below, the estimated duration of tutorials may be 90-120 min with necessary practical hands-on exercises (similar to academic lectures and practice sessions).

- LU-SSES01: RI/data centre energy and environmental impact related metrics and KPI. Mapping between energy related metrics and CO_2/Carbon footprint (or embedded footprint).
- LU-SSES02: API and information model (and metadata) for energy and environmental impact monitoring, including necessary knowledge of data and metadata management.
- LU-SSES03: Environmental sustainability and energy efficiency aspects related to the RI operation, along all RI lifecycle stages, including required/available metrics and target KPI, analysis of specific use cases.
- LU-SSES04: Tools for measuring and monitoring Energy Efficiency aspects of the computational work, such as Scaphandre, Code Carbon, Kepler and supporting libraries and monitoring dashboard applications.
- LU-SSES05: Knowledge and use/mastering of the environmental impact assessment tools and Research/Integrated Development Environment (RDE/IDE).
- LU-SSES06: Sustainable Architecture Design Principles (SADP) for digital RIs with environmental sustainability focus. Architecture and infrastructure design patterns, cloud based and cloud native services design principles.

5.2.3 Tutorial topics for technical staff of RI operator on monitoring Environmental Sustainability (RIOS)

The RI/data centre operational staff should have sufficient technical background to efficiently monitor and manage the facility operation and ensuring quality of services, delivered to researchers. The RI operational staff may benefit from attending the tutorials of groups GRIU for general competences SSES for technical development aspects. The following are specific tutorials that are related to operational staff responsibility:

- LU-RIOS01: Continuous data centre/RI monitoring, managing monitoring tools and infrastructure, reporting.
- LU-RIOS02: Workflow planning and optimisation on the data centre side, job load and energy prediction
- LU-RIOS03: Research Infrastructure Lifecycle Model (RILM) with the extension on RI evolution and procurement procedures and Termination stage that will require a number of procedures to discard or repurpose hardware, recycle data storage facilities, data migration or archiving in a potentially re-usable format.
- LU-RIOS04: Managing and monitoring energy supply and power Smart Grids,

- LU-RIOS05: Cooling, water, heat management approaches, methods and tools, maintaining and improving the facilities' efficiency.

5.2.4 Tutorials and executive briefings for the RI management roles (MEB)

Tutorials and executive briefings for the RI management should be short and visual and be ready for the management to understand the proposed idea or solution and make an informed decision as a result of discussion or in the future when the decision time will approach.

For this purpose, the tutorials and LUs related to environmental sustainability policies and regulations should be included (short version of LU-GRIU02 and LU-GRIU03) as well as the Shared Responsibility Model for Sustainability (LU-GRIU04) and Research Infrastructure Lifecycle Model (LU-GRIU05).

The importance of the necessary competencies for technical operational staff should also be presented in management briefings with reference to existing competence frameworks and available training courses and tutorials, in a brief form and well supported with visual and graphics materials. Such materials can be produced based on LU modules LU-CESA01, LU-CESA02.

5.2.5 General Environmental Sustainability Competences and Knowledge (Green and Environmental Sustainability Awareness - GESA)

This type of tutorial will be targeted to create environmental sustainability awareness for a wide spectrum of target professional research and academic audiences. GreenComp and partly UNESCO Education for Sustainable Development (ESD) program will provide a basis for such training. Due to the specifics of GreenComp definition, the Green Awareness tutorials will include interactive sessions to involve the attendees in the discussion about the GreenComp competences and how they can be used in their organisation, project, team or other specific use cases.

The following are suggested tutorial topics and LUs (some topics can be similar to the general user targeted tutorial but with the reduced technical details and time):

- LU-GESA01: European GreenComp Framework competence groups: (1) Embodying Sustainable Values, (2) Embracing Complexity in Sustainability, (3)Envisioning Sustainable Futures , (4) Acting for sustainability (60-90 minutes, including interactive session and gamification)
- LU-GESA02: SDG17 overview and existing initiatives and programs related to SDG04 Quality Education, and SDG09 Industry, Innovation and Infrastructure (20-30 minutes)
- LU-GESA03: Environmental sustainability policies and regulations: international policies and treaties, European regulations, national or local (15-20 minutes)
- LU-GESA04: Shared Responsibility Model for Sustainability (proposed by GreenDIGIT) as an instrument for defining and realising the interaction between all involved parties and stakeholders in the RI operation and use (10-15 minutes)

5.2.6 Defining programs for training events and workshops on environmental sustainability and energy efficiency for RIs

Training programs for target user or stakeholder groups can be constructed using suggested LUs and based on analysis and identification of the target RI needs, available services and user platforms. Training programs may address different RI lifecycle stages and correspondingly different sustainability tasks. The methodology for designing the customised curricula and training program will be developed during the next GreenDIGIT period in months M19-M36. The initial set of training modules will be delivered during the summer period.

6 Conclusion and future work

The work presented in this deliverable under Task 10.4 – Training Curricula Development Based on Required Skills for Users, Developers, and Managers forms the foundation for developing a structured approach to training on environmental sustainability and energy efficiency in digital research infrastructures (RIs). This effort is crucial in equipping researchers, developers, RI operators, and managers with the necessary technical and organizational competences to support sustainable digital infrastructure development and operation.

The initial work with the analysis of the GreenComp as described above allowed us to define some possible improvements to the current version of the GreenComp published in 2022. Contact has been established with the JRC team that developed GreenComp to discuss possible updates based on the complex of identified additional and technology and RI operation related competences. Preliminary, a first meeting has been planned in mid-April 2025.

The analysis of existing Green Competence frameworks revealed a gap in technical competences required for ensuring sustainability in RIs. To address this, GreenDIGIT has introduced a set of technical and engineering competences, aligned with the Reference Architecture for Sustainability and Sustainable Architecture Design Principles developed in WP4 and WP5. These competences are the basis for the proposed training modules and learning units presented in Chapter 5, covering different organizational roles throughout the RI lifecycle, with an initial focus on operational stage users and technical staff.

The initial set of training modules will be further refined and implemented during the next phase of the project. These modules will be piloted at various research and developer events, including the summer schools co-organized by GreenDIGIT in collaboration with partner RIs and projects. Additionally, training topics will incorporate hands-on exercises with digital tools and platforms developed within the project, ensuring practical applicability.

Further development of the environmental sustainability (green) competences will require involvement of the wider research digital infrastructures professional community, targeting to organise joint events and workshops, organise interactive discussions during summer schools. Major outcomes of the current deliverable can be used for initiating discussions on the social media LinkedIn, Twitter, Facebook, as well as workshops and tutorials organised by project partners during the top international conferences.

To maximize the impact of this work, the findings will be shared with the broader research community and cooperating projects, allowing for external feedback and potential collaboration on further refining the curricula. Efforts will be made to disseminate the results through academic and technical publications, possibly leading to a research paper on sustainability competences in digital RIs.

By advancing the training curricula and integrating sustainability-focused education into RI operations, GreenDIGIT aims to ensure long-term adoption of the best practices in sustainable research infrastructures. The knowledge and training materials developed in this task will contribute to broader efforts in achieving the environmental sustainability goals outlined in the ESFRI Roadmap 2026 and strengthening the sustainability competence base across the research and digital infrastructure communities.

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Annex A. Relevant European Digital Competences for Researchers and Educators

A.1. The European Competence Frameworks for Researchers

Table 6 provides an aggregated list of competences defined in the European Competence Frameworks for Researchers that are grouped into 7 groups reflecting different activities the researchers are involved and dealing with. In the context of the research and analysis in the current deliverable, the following competence groups may introduce the green related competences that will be beneficial for researchers to know and shape their research for compliance with sustainable development goals:

Table 6. European Competence Framework for Researchers - Main Competence Groups

1. Managing research 1. Mobilize resources 2. Manage projects 3. Negotiate 4. Evaluate research 5. Promote open access publications 2. M**aking an impact** 1. Participate in the publication process 2. Disseminate results to the research community 3. Teach in academic or vocational contexts 4. Communicate to the broad public 5. Increase the impact of Science on Policy and Society **3, Self-management** 1. Manage personal professional development 2. Show entrepreneurial spirit 3. Plan self-organization 4. Cope with pressure **4. Cognitive abilities** 1. Abstract thinking 2. Critical thinking 3. Analytical thinking 4. Strategic thinking 5. Systemic thinking 6. Problem solving 7. Creativity	**5. Work with others** 1. Interact professionally 2. Develop networks 3. Work in teams 4. Ensure wellbeing at work 5. Build mentor-mentee relationships 6. Promote inclusion & diversity **6. Managing research tools** 1. Manage research data 2. Promote citizen science 3. Manage intellectual property rights 4. Operate open-source software **7. Doing research** 1. Have disciplinary expertise 2. Perform scientific research 3. Conduct interdisciplinary research 4. Write research documents 5. Apply research ethics and integrity principles

A.2. The EU Framework of Digital Competences for Educators [48]

Table 7 provides an aggregated list of competences defined by the EU Frameworks of Digital Competence for Educators that are grouped into 6 groups reflecting different activities the educators are involved and dealing with. In the context of the research and analysis in the current deliverable, educators need to include aspects of environmental sustainability to build wide awareness and the right attitude to support environmental sustainability goals among learners.

Table 7. The EU Framework for Digital Competences for Educators

Area 1: Professional Engagement 1.1 Organisational communication 1.2 Professional Collaboration 1.3 Reflective Practice 1.4 Digital Continuous Professional Development	**Area 4: Assessment** 4.1 Assessment strategies 4.2 Analysing evidence 4.3 Feedback and Planning
Area 2: Digital Resources 2.1 Selecting digital resources 2.2 Creating and modifying digital content 2.3 Managing, protecting and sharing digital resources	**Area 5: Empowering Learners** 5.1 Accessibility and inclusion 5.2 Differentiation and personalisation 5.3 Actively engaging learners
Area 3: Teaching and Learning 3.1 Teaching 3.2 Guidance 3.3 Collaborative learning 3.4 Self-regulated learning	**Area 6: Facilitating Learners' Digital Competence** 6.1 Information and media literacy 6.2 Digital communication and collaboration 6.3 Digital content creation 6.4 Responsible use 6.5 Digital problem solving

The detailed definition of component competences is given below.

Area 1: Professional Engagement

1.1 Organisational communication
To use digital technologies to enhance organisational communication with learners, parents and third parties. To contribute to collaboratively developing and improving organisational communication strategies.

1.2 Professional Collaboration
To use digital technologies to engage in collaboration with other educators, sharing and exchanging knowledge and experience, and collaboratively innovating pedagogic practices.

1.3 Reflective Practice
To individually and collectively reflect on, critically assess and actively develop one's own digital pedagogical practice and that of one's educational community.

1.4 Digital Continuous Professional Development
To use digital sources and resources for continuous professional development.

Area 2: Digital Resources

2.1 Selecting digital resources
To identify, assess and select digital resources for teaching and learning. To consider the specific learning objective, context, pedagogical approach, and learner group, when selecting digital resources and planning their use.

2.2 Creating and modifying digital content
To modify and build on existing openly-licensed resources and other resources where this is permitted. To create or co-create new digital educational resources. To consider the specific learning objective, context, pedagogical approach, and learner group, when designing digital resources and planning their use.

2.3 Managing, protecting and sharing digital resources
To organise digital content and make it available to learners, parents and other educators. To effectively protect sensitive digital content. To respect and correctly apply privacy and copyright rules. To understand the use and creation of open licenses and open educational resources, including their proper attribution.

Area 3: Teaching and Learning

3.1 Teaching
To plan for and implement digital devices and resources in the teaching process, so as to enhance the effectiveness of teaching interventions. To appropriately manage and orchestrate digital teaching interventions. To experiment with and develop new formats and pedagogical methods for instruction.

3.2 Guidance
To use digital technologies and services to enhance the interaction with learners, individually and collectively, within and outside the learning session. To use digital technologies to offer timely and targeted guidance and assistance. To experiment with and develop new forms and formats for offering guidance and support.

3.3 Collaborative learning
To use digital technologies to foster and enhance learner collaboration. To enable learners to use digital technologies as part of collaborative assignments, as a means of enhancing communication, collaboration and collaborative knowledge creation

3.4 Self-regulated learning
To use digital technologies to support learners' self-regulated learning, i.e. to enable learners to plan, monitor and reflect on their own learning, provide evidence of progress, share insights and come up with creative solutions

Area 4: Assessment

4.1 Assessment strategies
To use digital technologies for formative and summative assessment. To enhance the diversity and suitability of assessment formats and approaches.

4.2 Analysing evidence
To generate, select, critically analyse and interpret digital evidence on learner activity, performance and progress, in order to inform teaching and learning.

4.3 Feedback and Planning
To use digital technologies to provide targeted and timely feedback to learners. To adapt teaching strategies and to provide targeted support, based on the evidence generated by the digital technologies used. To enable learners and parents to understand the evidence provided by digital technologies and use it for decision-making.

Area 5: Empowering Learners

5.1 Accessibility and inclusion
To ensure accessibility to learning resources and activities, for all learners, including those with special needs. To consider and respond to learners' (digital) expectations, abilities, uses and misconceptions, as well as contextual, physical or cognitive constraints to their use of digital technologies.

5.2 Differentiation and personalisation
To use digital technologies to address learners' diverse learning needs, by allowing learners to advance at different levels and speeds, and to follow individual learning pathways and objectives.

5.3 Actively engaging learners
To use digital technologies to foster learners' active and creative engagement with a subject matter. To use digital technologies within pedagogic strategies that foster learners' transversal skills, deep thinking and creative expression. To open up learning to new, real-world contexts, which involve learners themselves in hands-on activities, scientific investigation or complex problem solving, or in other ways increase learners' active involvement in complex subject matters.

Area 6: Facilitating Learners' Digital Competence

6.1 Information and media literacy
To incorporate learning activities, assignments and assessments which require learners to articulate information needs; to find information and resources in digital environments; to organise, process, analyse and interpret information; and to compare and critically evaluate the credibility and reliability of information and its sources.

6.2 Digital communication and collaboration
To incorporate learning activities, assignments and assessments which require learners to effectively and responsibly use digital technologies for communication, collaboration and civic participation.

6.3 Digital content creation
To incorporate learning activities, assignments and assessments which require learners to express themselves through digital means, and to modify and create digital content in different formats. To teach learners how copyright and licenses apply to digital content, how to reference sources and attribute licenses.

6.4 Responsible use
To take measures to ensure learners' physical, psychological and social wellbeing while using digital technologies. To empower learners to manage risks and use digital technologies safely and responsibly.

6.5 Digital problem solving
To incorporate learning activities, assignments and assessments which require learners to identify and solve technical problems, or to transfer technological knowledge creatively to new situations.

A.3. Digital Competences and Data Literacy

In the context of digital transformation and growing AI-based automation, all professional profiles should possess sufficient levels of digital competences and skills to operate successfully in Industry 4.0. The EC study and report on “Digital Competences for Citizen” (DigComp) published in 2018[20] provides good advice for addressing both digital skills and data skills in professional workplace training and vocational education. An important part of digital competences is understanding the role of data and processes related to data handling in modern applications, social media, industrial processes, research, and specifically how data are used in AI based decision making and control. Special training and skills development must be focused on data processing and management issues.

Table 8. Digital Competences defined in DigComp 2.1

Competence area DigComp	**Competence**
Competence area 1: Information and data literacy	1.1 Browsing, searching and filtering data, information and digital content
	1.2 Evaluating data, information and digital content
	1.3 Managing data, information and digital content
Competence area 2: Communication and collaboration	2.1. Interacting through digital technologies
	2.2. Sharing through digital technologies
	2.3. Engaging in citizenship through digital technologies
	2.4. Netiquette
	2.4 Collaborating through digital technologies
	2.5 Netiquette
	2.6. Managing digital identity
Competence area 3: Digital content creation	3.1 Developing content
	3.2 Integrating and re-elaborating digital content
	3.3 Copyright and licenses
	3.4 Programming
Competence area 4. Safety	4.1. Protecting devices
	4.2. Protecting personal data and privacy
	4.3. Protecting health and well-being
	4.4. Protecting the environment
Competence area 5. Problem Solving	5.1. Solving technical problems
	5.2. Identifying needs and technological responses
	5.3. Creatively using digital technologies
	5.4. Identifying digital competence gaps

Annex B. Using EDSF methodology to collect and analyse job market and competence related data

B.1. EDISON methodology to collect and analyse job market and competence related data

To verify existing frameworks and potentially identify new competences, different sources of information have been investigated:

- First of all, job advertisements that represent the demand side for green or environmental sustainability aware positions and data management specialists and based on practical tasks and functions that are identified by organisations for specific positions. This source of information provided factual data to define demanded competences and skills.
- Structured presentation of environmental aware/related competences and skills produced by different studies as mentioned above, in particular GreenComp based definition of green/sustainability competences. This information was used to correlate with information obtained from job advertisements.
- Blog articles and community forums discussions that represented valuable community opinion. This information was specifically important for defining practical skills and required tools.

The following approach has been used when analysing the job advertisement data

1) Collect data on required competences and skills
2) Extract information related to competences, skills, knowledge, qualification level, and education; translate and/or reformulate if necessary
3) Split extracted information on initial classification or taxonomy facets, first of all, on required competences, skills, knowledge; suggest mapping if necessary
4) Apply existing taxonomy or classification: for the purpose of this study, we used skills and knowledge groups as defined by the GreenComp but aligned with EDSF definition of Data Science and research related competences
5) Identify competences and skills groups that do not fit into the initial/existing taxonomy and create new competences and skills groups
6) Do clustering and aggregations of individual records/samples in each identified group
7) Verify the proposed competences groups definition by applying to originally collected and new data
8) Validate the proposed competence framework via community surveys and individual interviews.

B.2. Job Market Analysis for Green Competences Demand and Awareness

This section provides a summary of the information extracted from the green and environmentally aware vacancies analysis. Mapping of vacancies information to competences, skills and knowledge items was done manually using simple text extraction and content ordering in Excel. The Excel workbooks are available in the DSP-CF git folder[6]. This study was done as a part of the BSc graduation project in term 2023/2024 at the University of Amsterdam (Faculty of Science) and presented at the EDULEARN2024 Conference[31].

B.2.1. Data Collection

For the job market analysis, the data is collected from the popular job employment portal Indeed.com. Using the Python tool Selenium, a Chrome page is accessed and indeed.com is opened. Selenium is used due to potential Captcha checks that indeed.com provides. This is the most important factor on why Selenium is chosen over the basic 'requests' library.

The vacancies are filtered for 'Sustainability data'. The main function takes a query containing the selected filter words. query is inserted into the base URL. In the main function, a search depth can be set to the desired amount of vacancies that are needed. In this case, 10 vacancies are requested.

The web page contains about 7 vacancy titles with a preview of the description. The retrieved HTML code is parsed using the HTML.parser using BeautifulSoup(). This parser is used to store the link to each vacancy in a data frame containing: a job ID, URL to job the job vacancy and the date of scraping. The job ID is manually assigned using an ascending pattern (001,002, ... n), the URL is acquired by finding a regular pattern found in the URL. In this case, each link is found using the find() find_all() methods. Links that contain a certain pattern, for example 'clkijk', is a link to a vacancy. The date is stored using the datetime library from python. Every entry is stored in a data frame. When the code is called again, at first a check is executed if the link already exists in the data frame to not accept duplicates.

With this data frame, a new function is called that uses a loop over the rows in the data frame. In every iteration, the HTML content is fetched from the URL to the specific vacancy. The HTML content is then stored in a separate file within a specific HTML directory that holds all the HTML contents. The filename is an ID, followed by the date, which is also acquired from the original dataframe.

B.2.2. Full vacancy approach

In order to retrieve the full vacancy text, Beautifulsoup is again used to parse the stored HTML files. Specifically, the get_text function is used to retrieve only the text from the HTML source. For each file in the HTML directory, the text is retrieved and stored in a new text directory. The name of each file is the same, but now stored in a new directory. For current job vacancy analysis , only the retrieved text was used. The full data collection pipeline is shown in Figure 7.

---

[6] https://github.com/EDISONcommunity/EDSF/tree/master/data-stewardship-professional-competence-framework

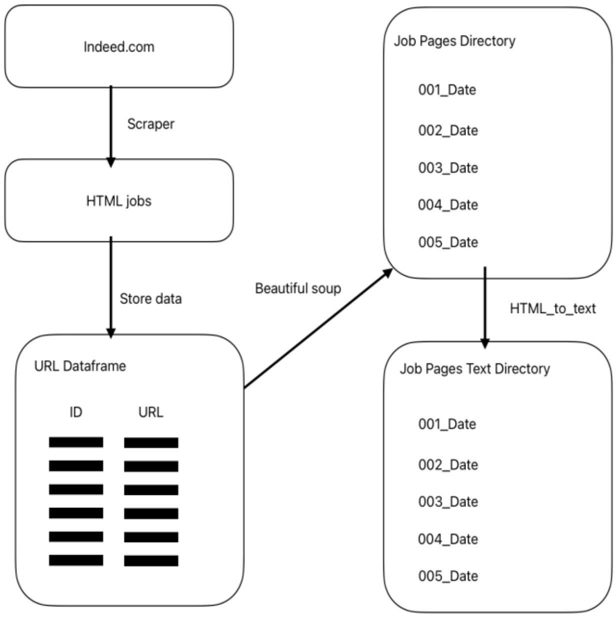

Figure 7. Data collection pipeline

B.2.3. Processing GreenComp related vacancies

For the next step, a detailed understanding of the GreenCompetence framework is needed. The green competence framework contains 12 competences divided into 4 competence groups. Within this project, two separate approaches are used. For the first one, the original text, provided by GreenComp is used for the analysis. This is the most straightforward approach. For the second one, a new strategy is proposed by making a custom vocabulary, which will be explained later in this section.

Full competence text

The first approach consists of using the full text paragraph for each. A separate directory is made with a file for each competence. The competences are labelled with a unique ID using the prefix "GCF-*" (Green Competence Framework) as shown in Figure 8. For each competence, not only the descriptor, but the entire paragraph in the GreenComp document is used. Each competence file contains a detailed description, and for each competence knowledge, skills and attitudes are listed. For example, in Figure 9. GFC_1 paragraph. the paragraph for competence 'Valuing sustainability' is shown

ID	Competence
GCF_01	Valuing sustainability
GCF_02	Supporting fairness
GCF_03	Promoting nature
GCF_04	Systems thinking
GCF_05	Critical thinking
GCF_06	Problem framing
GCF_07	Futures literacy
GCF_08	Adaptability
GCF_09	Exploratory thinking
GCF_10	Political agency
GCF_11	Collective action
GCF_12	Individual initiative

Figure 8. Competences IDs (prefic GCF - GreenCompetence Framework)

```
GCF_01.txt

4.1.1 Valuing sustainability
Descriptor (1.1): To reflect on personal values; identify and explain how values vary among people and over time, while critically evaluating how they align with sustainability values
Valuing sustainability aims to foster reflection on values and perspectives in relation to concerns for sustainability. In this context, learners can articulate their values and consider the
ir alignment with sus tainability as the common goal.
Valuing sustainability could be defined as a metacompetence, since its primary aim is not to teach specific values, but make learners realise that values are constructs and people can choose
 which values to prioritise in their lives31.
Valuing sustainability enables learners to reflect on their way of thinking, their plans, and their actions. It asks them whether these cause any harm and are in line with sustainability val
ues and thus contribute to sustainability. It offers learners an opportunity to discuss and reflect on values, their variety and culturedependence.

Examples of knowledge (K), skills (S) and at titudes (A):
K: knows the main views on sustainability: anthropocentrism (humancentric), technocentrism (technological solutions to ecological problems) and ecocentrism (naturecentred), and how they infl
uence assumptions and arguments;
S: can articulate and negotiate sustainability values, principles and objectives while recognising different viewpoints;
A: is prone to acting in line with values and principles for sustainability.
For example: Given the apparent tensions between sustainability and consumerism based on the use of natural resources, everybody should be able to contemplate what impact buying fast fashion
 or taking a flight for a weekend getaway would have at system level (SDG 12).
```

Figure 9. GFC_1 paragraph.

Custom Vocabulary

The second approach is a novelty approach that uses a Role and Activity Based (RAB) approach to custom vocabulary creation. The structure of the vocabulary is based on the CEN-CENELEC workshop agreement CWA 16458-1[49] where European ICT professional roles defined with key competences and tasks.

Using GPT-4 to generate vocabulary

To generate the vocabulary, a RAB-approach is followed. For this specific project, since the time restriction of three months, GPT-4[50] is used to generate the first version of this vocabulary. This choice is made over domain specific LLMs. This decision is made since the domain specific performance of GPT-4 shows some promising results. In this study, we specifically investigated the importance of synonym perturbation by varying the prompt with synonyms, without changing the original semantic meaning.

The prompts are designed considering the RAB-approach, which means that common job titles that are extracted using the scraper. These job titles can be considered the Roles. As of Activity, keywords from the competences GreenComp, are considered. The output that GPT-4 delivers, is manually checked and validated with the information extracted from the CEN-CENELEC workshop document. This means that some suggestions from GPT-4 are removed due to their unlikeliness of being a valid attitude that is displayed in that certain Role. With this information, the prompts are stated as follows:

> *Give examples of attitudes/skills/knowledge in relation to ’Activity’ for the company role of ’Role’*

With the consideration of using synonyms, the sentence is separated into the following sections to maintain the original syntax:

> **Verb**: Give
> **Noun**: Examples
> **Preposition/Phrase**: Of
> **Noun**: Attitudes/skills/knowledge **Preposition/Phrase**: In relation to **Noun**: ’Activity’
> **Preposition/Phrase**: For the company role of
> **Noun**: ’Role’

For this project, the choice was made to focus on using Synonyms of the noun ’Activity’. This means that using synonyms for the selected keywords in the Green- Comp framework are used for making the vocabulary. For example, for the Activity.

’Valuing sustainability’, synonyms like ’Environmental stewardship’ are used. In Figure 10. Prompts for Role "Sustainability Data Manager"., the example is given for the Role ’Sustainability Data Manager’.

Keyword GreenComp
Give examples of attitudes in relation to 'Valuing Sustainability' for the company role of 'Sustainability Data Manager'
Give examples of skills in relation to 'Valuing Sustainability' for the company role of 'Sustainability Data Manager'
Give examples of knowledge in relation to 'Valuing Sustainability' for the company role of 'Sustainability Data Manager'
Synonym
Give examples of attitudes in relation to 'Environmental Stewardship' for the company role of 'Sustainability Data Manager'
Give examples of skills in relation to 'Environmental Stewardship' for the company role of 'Sustainability Data Manager'
Give examples of knowledge in relation to 'Environmental Stewardship' for the company role of 'Sustainability Data Manager'

Figure 10. Prompts for Role "Sustainability Data Manager".

With this method, multiple roles are considered and this results in the following: For GCF_01, this terms like ’Valuing sustainability’, ’Consumerism’ and ’System Level Impact’ are being used as Activity for several roles. The selected responses were used to build and investigate the entire vocabulary.

The goal of making a custom vocabulary is to reduce noise by leaving out irrelevant terms, improve semantic understanding and the handling of specific synonyms and variations. For example, ’software development’ and ’coding’ can be used interchangeably, but this will not be recognised by TF-IDF. When using the custom vocabulary, such synonyms can be handled. The improvement in semantic understanding does not have any influence in the usage of TF-IDF, but this does have positive influence on word embedding models.

B.2.4. Pre-processing Vacancy text

One of the most important steps in NLP is preprocessing the text data. Preprocessing in NLP refers to an array of techniques that are applied to raw text data. This step is done before further processing or analysis. The goal of this step is to transform the raw data into clean, usable data. For data to be usable in case of finding similarity, it needs to be the same on a syntactic level. To achieve this, the following steps are made:

- Lowercase
- Remove punctuation
- Remove newline characters
- Tokenize
- Lemmatize
- Remove stop words

In count models, text preprocessing, like removing stop words and punctuation, lowercasing, and lemmatization, is crucial to reduce feature dimensionality and focus on meaningful words. Word embeddings, learn representations based on word contexts, making preprocessing steps less critical, as the model captures semantic relationships even with raw text. This is why in the case of TF-IDF, the choice is made to preprocess the text, but for using MP_net, this step is skipped.

B.2.5. Vectorize and compare

The directory, where the full text of all the vacancies is stored, is looped over. For each file in the directory, the TfidfVectorizer from the sklearn library is used to transform the text data into a TF-IDF matrix. This vectorizer is trained (fit) on all text data, including both the job vacancy text and the competence definitions. The competences are defined in text files within a specified directory. The definitions are extracted and added into the dictionary with each competence ID as a key. For each key in the dictionary, the definition is vectorized with the TFidfVectorizer.

After vectorizing the texts, cosine similarity between the TF-IDF vector of the job vacancy and each competency's TF-IDF vector is calculated. Cosine similarity was chosen over Euclidean distance since cosine similarity is not effected by the length of a vector and Euclidean distance does.

The vectorization and similarity calculation process is shown in Figure 12

```
def calculate_similarity(vacancy, competence):
    vacancy_tfidf = vectorizer.transform([vacancy])  # Transform to TF-IDF
    competence_tfidf = vectorizer.transform([competence])  # Transform to TF-IDF
    similarity = cosine_similarity(vacancy_tfidf, competence_tfidf)
    return similarity[0][0]

# Create a list to store similarity scores
similarity_scores = []

# Calculate similarity for each competence and store the scores
for competence, definition in competence_definitions.items():
    preprocessed_definition = preprocess_text(definition)
    similarity = calculate_similarity(preprocessed_vacancy, preprocessed_definition)
    similarity_scores.append(similarity)
```

Figure 11. Vectorisation and similarity.

Finally, the similarity score for each competence is visualized in a radar chart. The highest similarity score is mapped to one, to highlight nuances in the scores. The normalized similarity scores are then stored in a data frame (Figure 13) to go to the next step of visualization in a radar chart. In addition, the highest similarity score is shown, in order to give some extra context to the graph. The radar charts are visualized in the results section.

	Competence	Similarity
0	GCF_01	1.000000
1	GCF_02	0.593398
2	GCF_03	0.403587
3	GCF_04	0.754359
4	GCF_05	0.647948
› 5	GCF_06	0.576410
6	GCF_07	0.572612
7	GCF_08	0.685690
8	GCF_09	0.498717
9	GCF_10	0.699542
10	GCF_11	0.704904
11	GCF_12	0.588583

Figure 12. Normalised similarity score.

B.3. Similarity between full vacancy and GreenComp full paragraph

Figure 13 and Figure 14 illustrate two examples of matching similarity between the generated competences refence vocabulary and a few real job vacancies Selected best suited for our study using correspondingly GreenComp full paragraph competences definition and using constructed controlled vocabulary.

Figure 13. Similarity between full vacancy and GreenComp vacancy description

Figure 14. Similarity between full vacancy and constructed custom vocabulary

Above, the similarity score between vacancies and the full paragraphs of the GreenComp Framework paragraphs are visualized. In order to understand the visualizations, some details need to be considered. Since the similarity scores are normalized to 1, the relative difference in similarity scores is amplified. That is why in all radar charts, the competence with the highest similarity score is shown after the vacancy title. This highest score is mapped to 1.0. Since the highest similarity scores vary between 0.07 and 0.16, these visualizations are not decisive. To increase the similarity scores, the RAB-approach was created.

The similarity scores between the Custom vocabulary and vacancies illustrated that overall, the highest similarity score, where the normalized score is mapped to 1.0, is originally scoring between 0.2 and 0.26. The highest scoring competence over all vacancies is GCF_01 “Valuing Sustainability”. Another higher scoring competence is GCF_04 “System Thinking”. In all vacancies, most competences show some similarity, all around the same factor .5 of the highest scoring similarity score.

Annex C. University Programs and Courses with Sustainability and Energy Efficiency related topics

The table below contains a set of university courses among project partner universities and other known courses that contain elements of energy efficiency and/or environmental sustainability in programs related to Computer Science, Software Engineering or Communication and Computer Networks.

University or Institution	Program or Course name + General description and or content + Learning Outcome or Aim/Goal	Possible use for the RI/research community
University of Thessaly	Course name: **Advanced Topics in Computer Networks** Link https://www.e-ce.uth.gr/studies/undergraduate/courses/ece555/?lang=en The purpose of this course is to introduce students to immerse themselves in the mechanisms and techniques for transmitting information under various conditions in wireless environments. In particular, the class focuses on research issues in every layer of the OSI networking stack and how these can be studied using the software tools that are taught in the class. The students will get hands-on experience through the utilization of sophisticated Software Defined Radio (SDR) devices (USRP, Pluto, etc.) in wireless testbed environments. After the successful completion of this class, the student will be able to • understand sophisticated wireless networking technologies and topologies. • understand the wireless medium particularities as well as the special challenges that result from the wireless medium comparing to the wired one. • understand better special research topics and deal with challenges of various wireless networking architectures (dynamic frequency selection, spectrum sensing etc.) • develop mechanisms in modern wireless communication for resources optimization, through wireless testbeds and SDR devices.	The developed mechanisms (final projects) in the wireless testbed environments mainly deal with performance optimizations. However, the overall increase in the performance in a wireless network reflects also on the energy efficiency as well.
University of Thessaly	Course name: **Wireless Communications** Link https://www.e-ce.uth.gr/studies/undergraduate/courses/ece436/?lang=en This class presents and analyses topics from the area of wireless communications and networking, their underlying existing every-day technologies (like IEEE 802.11), and motivates a deep analysis on their principles. The laboratory part of this class and the final project	The developed mechanisms (final projects) in the wireless testbed environments mainly deal with performance optimizations. However, the overall increase in the performance in a

	involve the students with the development of sophisticated techniques (adaptive modulation, rate adaptation, dynamic packet sizes etc.) for resource optimization in wireless networks through the utilization of research infrastructures (wireless testbed)	wireless network reflects also on the energy efficiency as well.
	After the successful completion of this class, the student will be able to • understand comprehensively every-day wireless networking technologies such as Wi-Fi. • understand the wireless medium particularities as well as the special challenges that result from the wireless medium comparing to the wired one. • understand better special research topics and deal with challenges of various wireless networking architectures (infrastructure, ad-hoc etc.), signal propagation models, rate adaptation, adaptive modulation and power control. • develop mechanisms in modern wireless communication through the use of open-source drivers for resources optimization.	
University of Amsterdam	Course name: **Large Systems** Link: https://coursecatalogue.uva.nl/xmlpages/page/2024-2025-en/search-course/course/119371	GREENDIGIT results can provide new lecture topics focused on energy efficient operation of OpenStack based research infrastructures.
	Description: This Master's course provides comprehensive instruction in managing, configuring, and administrating large data centres	
	Learning outcome: Students will acquire the skills to design, operate, and manage virtualized environments, such as OpenStack data centres, ensuring both efficiency and reliability.	
University of Amsterdam	Course name: **Energy Efficient Edge Computing** **Link:** https://coursecatalogue.uva.nl/xmlpages/page/2024-2025-en/search-course/course/119886	
	Description: This Master's course delves into efficient edge resource management through the integration of hardware-software co-design and design space exploration.	
	Learning outcome: Students learn to design algorithms that enable the efficient deployment of applications on edge computing resources.	
TU Wien, Austria	Course name: **AI/ML in the era of Climate Change** Link: https://tiss.tuwien.ac.at/course/courseDetails.xhtml?dswid=3245&dsrid=375&semester=2023W&courseNr=194125	
	Description: This course explores how AI workloads impact the sustainability of backend infrastructures, such as data centres. It focuses on developing resource-	

	efficient methods for the life cycle management of AI workloads. Additionally, it covers how to leverage AI to address climate change issues. **Learning outcome:** Students learn resource-aware AI model training and the creation of energy-efficient MLOps and inference pipelines. The course also covers leveraging AI algorithms to model scientific problems related to climate change.	
Vrij Universiteit Amsterdam	**Green Lab** https://research.vu.nl/en/courses/green-lab-4 Teaches students to directly experiment with energy consumption of software **Intended Learning Objectives**: VU-GL-O1. Learn the principles of Empirical Software Engineering. (Knowledge and understanding) VU-GL-O2. Be able to operate in a lab environment and build a successful experiment for software energy consumption. (Applying knowledge and understanding) (Making judgements) (Lifelong learning skills) VU-GL-O3. Become familiar with relevant research problems in the field of Green Software Engineering. (Knowledge and understanding) VU-GL-O4. Understand and measure the impact of software over energy consumption. (Applying knowledge and understanding) (Making judgements) Teaching methods: • Team work • Carry out experiments on software energy consumption in a controlled environment. Training for data analysis and visualisation	Connects with the topic of energy and power consumption metrics, and measurement methodologies
Vrij Universiteit Amsterdam	**Digitalisation and Sustainability** https://research.vu.nl/en/courses/digitalization-and-sustainability-4 Teaches basic concepts related to digitalization and sustainability such as the notions of sustainable software and software for sustainability, how to frame sustainability-quality concerns in the design of digital solutions, and how to assess sustainability impacts **Intended Learning Objectives:** VU-DS-O1. Familiarize with basic knowledge about digitalization and digital transformation, sustainability, and the role of digitalization in achieving business and other sustainability goals within society and organizations (Knowledge and understanding; Applying knowledge and understanding). VU-DS-O2. be able to reason about the technology and business-related digitalization and sustainability concerns, and apply their reasoning to a concrete project (Applying knowledge and understanding; Making judgments).	Connects with the topic of energy and power consumption metrics, and measurement methodologies; links to shared responsibility model.

	VU-DS-O3. have a basic understanding of the types of sustainability impacts of digital solutions, so to identify and assess the trade-offs between the different sustainability concerns addressed by digital solutions (Knowledge and understanding; Applying knowledge and understanding; Making judgments). VU-DS-O4. be able to write a scientific report about a concrete digitalization-and-sustainability project in a group of students (Applying knowledge and understanding; Making judgments; Communication skills). VU-DS-O5. be trained to (i) explore the problem and solution space in the digital transition of a specific sector/domain, and (ii) identify and address a set of relevant sustainability goals (Applying knowledge and understanding; Making judgments; Learning skills). VU-DS-O6. Be able to reflect critically on what learned, its impact in society, and express own motivated opinions (Applying knowledge and understanding; Making judgments; Communication skills; Learning skills) Teaching methods: • live lectures, • flipped-classes • Teamwork	
Twente University	**Green Software Development** https://utwente.osiris-student.nl/onderwijscatalogus/extern/cursus?cursuscode=202400609&collegejaar=2024&taal=en	Connects with the topic of energy and power consumption metrics, and measurement methodologies; links to shared responsibility model.
	Teaches a core set of topics on sustainability and software engineering, energy, power, performance engineering, energy efficiency requirements, tactics and strategies to reduce energy consumption in software development, and green AI, based on foundational as well as state-of-the-art results.	
	Intended Learning Objectives: TU-GSD-O1. Explain the five dimensions of sustainability and their relationship to software TU-GSD-O2. Measure and estimate the energy consumption of software systems TU-GSD-O3. Design and conduct experiments that help identify resource bottlenecks TU-GSD-O4. Apply well-understood tactics, patterns, and techniques to reduce software energy consumption TU-GSD-O5. Specify requirements for resource usage that are understandable, feasible, and verifiable TU-GSD-O6. Discuss open issues that have not yet been tackled by research in the area	
TUM	sustAInability	

	https://campus.tum.de/tumonline/ee/ui/ca2/app/desktop/#/slc.tm.cp/student/courses/950767805?$scrollTo=toc_overview	
	After successful participation in this course, students are able: ● to independently acquire knowledge and to put their knowledge, particularly in the context of artificial intelligence and sustainability, into practice e.g. in the form of written essays or presentations in class ● to systematically plan, design, and implement solutions with respect to sustainability and artificial intelligence (AI) in a team project to apply their knowledge ● to work together in an interdisciplinary team and to present their project results in a public pitch	
TUM	Sustainable Supply Chain Management	
	https://campus.tum.de/tumonline/ee/ui/ca2/app/desktop/#/slc.tm.cp/student/courses/950766908?$scrollTo=toc_overview	
	The goal of this course is to introduce students to concepts, methods, and tools of managing the sustainability of supply chains. It gives an overview over the relevant literature as well as valuable insights from practice. Moreover, it fosters the students' understanding of and sensitization for trade-offs in the sustainability context of supply chains by highlighting different roles and perspectives. The course also improves the students' presentation and discussion skills. Therefore, it provides the participants not only with the necessary knowledge to critically reflect on sustainability issues of supply chains but also with the opportunity to enhance their soft skills	
TUM	Digital Transformation & Sustainability https://campus.tum.de/tumonline/ee/ui/ca2/app/desktop/#/slc.tm.cp/student/courses/950766435?$scrollTo=toc_overview	
	In this seminar you will: • develop an understanding of the drivers and inhibitors of sustainability • get practical insights into sustainability strategy making and planning • get hands-on experience in conducting a major case study with a real organization • work in a team • get real-life experience in writing and presenting a case study report	