GreenDIGIT: Towards Environmentally Sustainable Research Infrastructures

Greening Digital Infrastructures with Sustainable Architecture and Design Principles

GreenDIGIT

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Outline

- GreenDIGIT project scope and goals
  - Founding EU ESFRI Research Infrastructures: SoBigData, EBRAINS, SLICES, EGI
- Shared Responsibility Model for Sustainability
  - RI Role and actors definition: RI providers/operators – Research applications developers - Researchers
- Sustainability by Design: Infrastructure components and aspects to be addressed
  - Research Infrastructure Lifecycle Model (RILM)
- Standardisation on Environmental Sustainability and technical requirements
- Monitoring and metrics for Energy Efficiency optimisation and Environmental Impact

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Sustainability Aspects: Energy Efficiency – Decarbonisation – Environmental Impact

- **Energy Efficiency of Digital Infrastructures**:
  - **Definition**: This refers to optimizing digital infrastructures to consume as little energy as possible for a given workload or service. It's about achieving more computational or storage results with less energy input.
- **Decarbonization of Digital Infrastructures**:
  - **Definition**: This specifically targets the reduction of carbon emissions associated with the operation and maintenance of digital infrastructures.
- **Reducing Environmental Impact of Digital Infrastructures**:
  - **Definition**: This is a more comprehensive consideration of the various ways digital infrastructures might affect the environment, going beyond just energy consumption and carbon emissions.

Architecture, Design,
Recommendations

Operation,
Monitoring, KPI

Lifecycle, Policy,
Training

GreenDIGIT project (2024-2027) – Objectives

- **O1: Assess the status and trends** of low impact computing within 4 DIGIT RIs (EGI, SLICES, SoBigData, EBRAINS) and wider ESFRI community, to produce **recommendations and roadmaps** for RIs green transition.
- **O2: Provide reference architecture and design principles**, reflecting on the **whole RI lifecycle** and including the digital infrastructure components.
- **O3: Develop new and innovative technologies, methods, and tools** for digital **service providers** within European Research Infrastructures.
- **O4: Develop and provide for researchers the tools** to support the design and execution of environmental sustainability aware scientific applications with Open Science and FAIR data management considerations.
- **O5: Educate and support RI service providers and researchers** about good practices on environmental impact conscious lifecycle management and operation of infrastructures and services.

Importance of the Architecture definition

- Architecture is a way to coordinate/synch/unite
  - Developers of Infrastructure and Applications
  - Operators
  - Users/Researchers
  - Policy and decision makers
  - Refer to TOGAF architecture principles (as an approach accepted by the majority of businesses)
- A basis for linking standards and regulations to architecture functional components
  - Ensure compliance of the designed/developed RI and services (including for suitability for audit and certification)

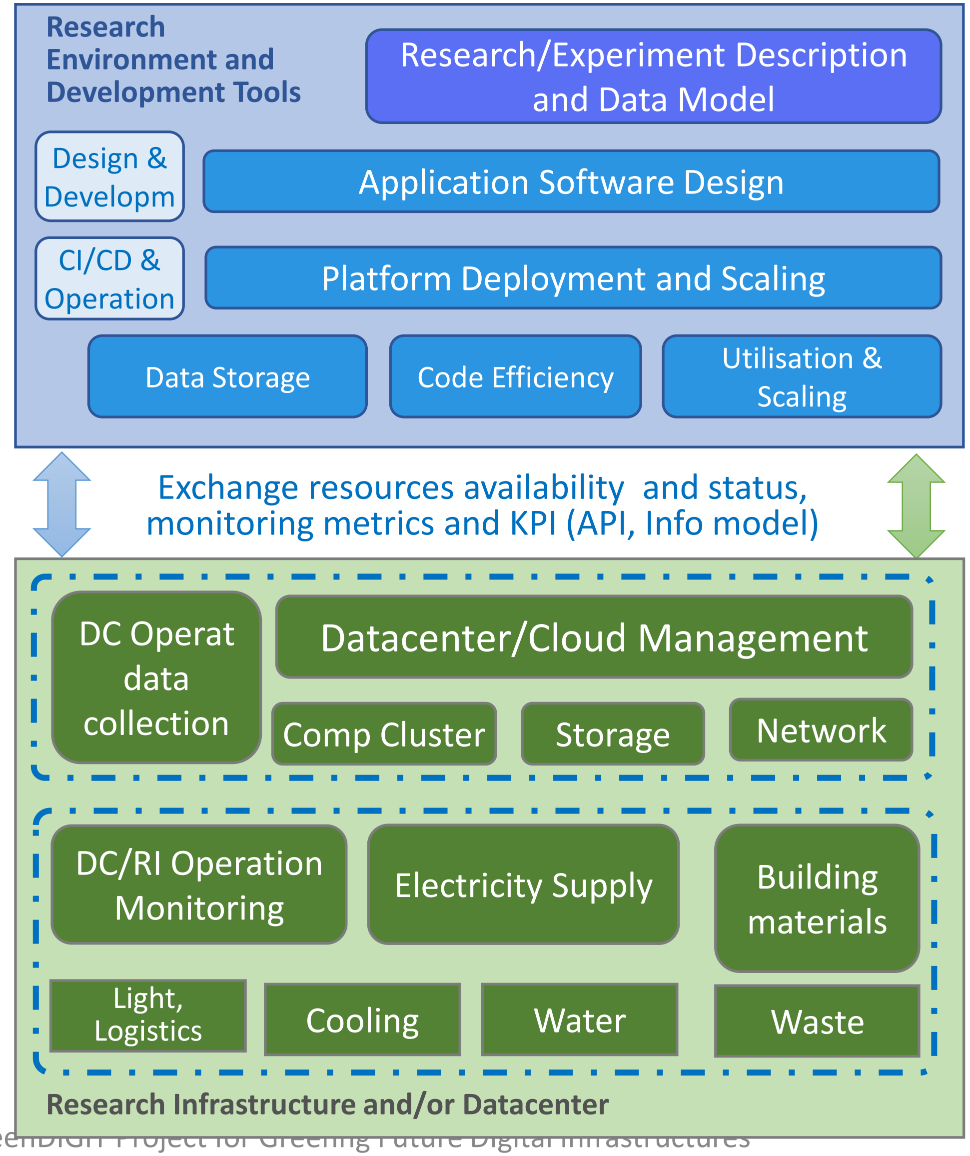
GreenDIGIT Architecture Definition Methodology

- General view on the RI Ecosystem Optimisation and Green IT
  - **Horizontal, vertical, lifecycle**
  - RI Operators and Researchers
  - RI continuum: (Research Object) – Sensor - (RAN) – Edge – Cloud – Workflow - Researcher
- Sustainable architecture design principles
  - As a basis for modelling and metrics for RI infrastructure operation and optimisation
  - **Shared Responsibility Model**: RI provider/operator and Researchers/Projects
  - **Sustainability by design** – A novel concept to be introduced to address different aspects and stages
- Linkage with existing Standards and Regulations to ensure Sustainable Architecture Design principles support compliance with the standards, regulations and audit
  - To provide the opportunity for RI/datacenter operation (and design) optimisation (through the whole lifecycle)
- System Engineering and Design (thinking) approach in Green research and technologies
  - **Sustainable (Durable) Architecture Design Principles (SADP)**

Shared Responsibility in Sustainability – Reflecting Operational and Management Aspects and Roles

Users responsible for sustainability ***on*** the RI

Providers responsible for the sustainability ***of*** the RI



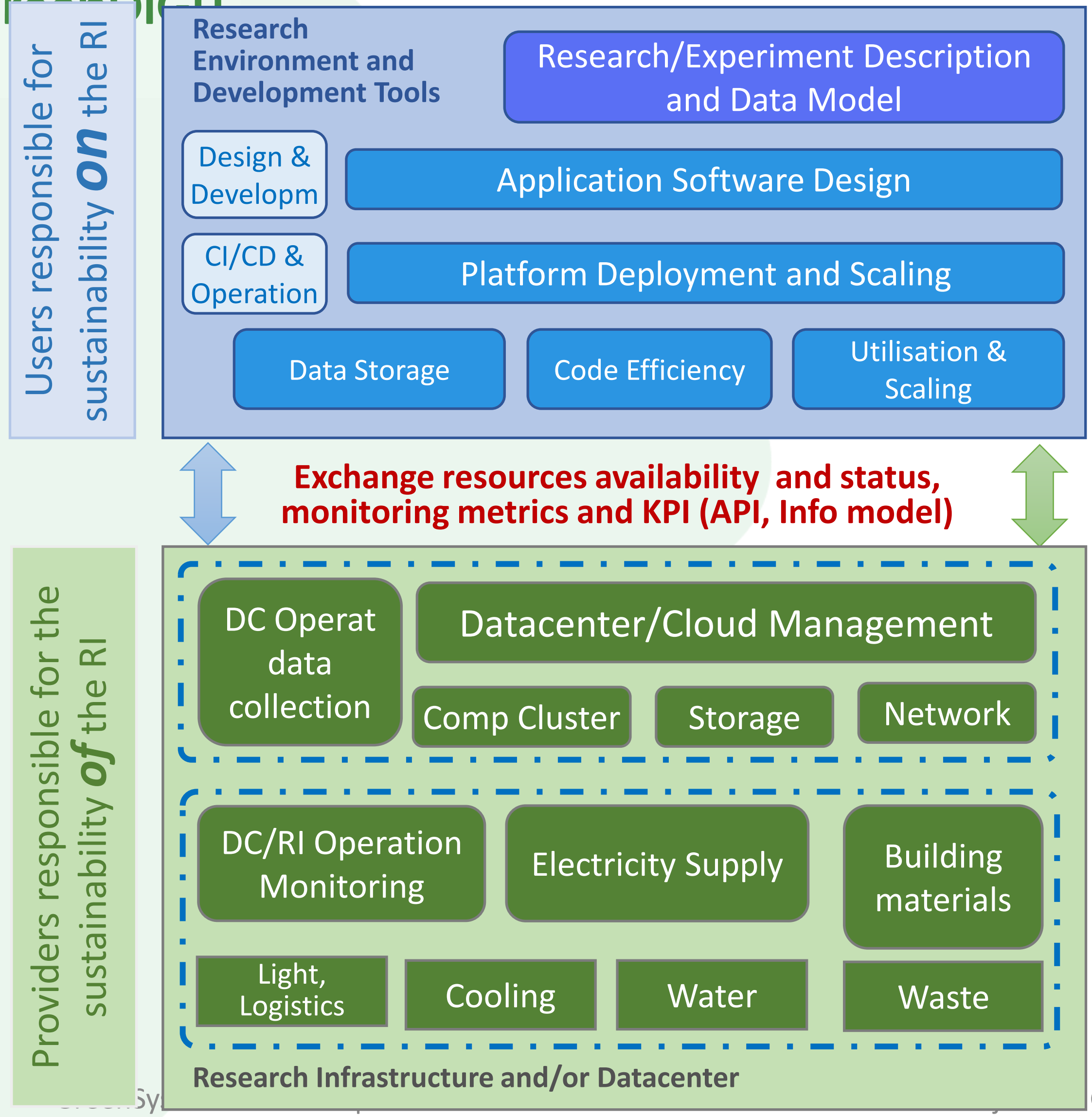
Standards and regulations
Software Development Quality and Design Patterns

Project/Researcher Responsibility:
Applications Development, Deployment, Operation, Energy usage and KPI monitoring

Provider/Operator Responsibility:
Research Infrastructure or Datacenter, Monitoring Energy and environmental impact metrics and KPI

Standards and regulations
Datacenter and RI Building and Operation

Shared Responsibility in Sustainability – Main Role Groups



Project/Researcher Responsibility:
- Applications Development,
- Deployment, Jobs submission & Energy Efficiency optimisation
- Operation, Workflow execution
- Energy usage and KPI monitoring

Experimenter/Researcher Demand:
- Access to datacenter (internal) monitoring data and custom configuration
- Energy usage and KPI & metrics monitoring

Provider/Operator Responsibility:
- Operation of Research Infrastructure
- or Datacenter,
- Monitoring Energy and environmental impact metrics and KPI
- Waste
- Lifecycle and evolution

Actors:

Operator group
- Facility owner
- Datacenter operator
- RI (overlay) operator

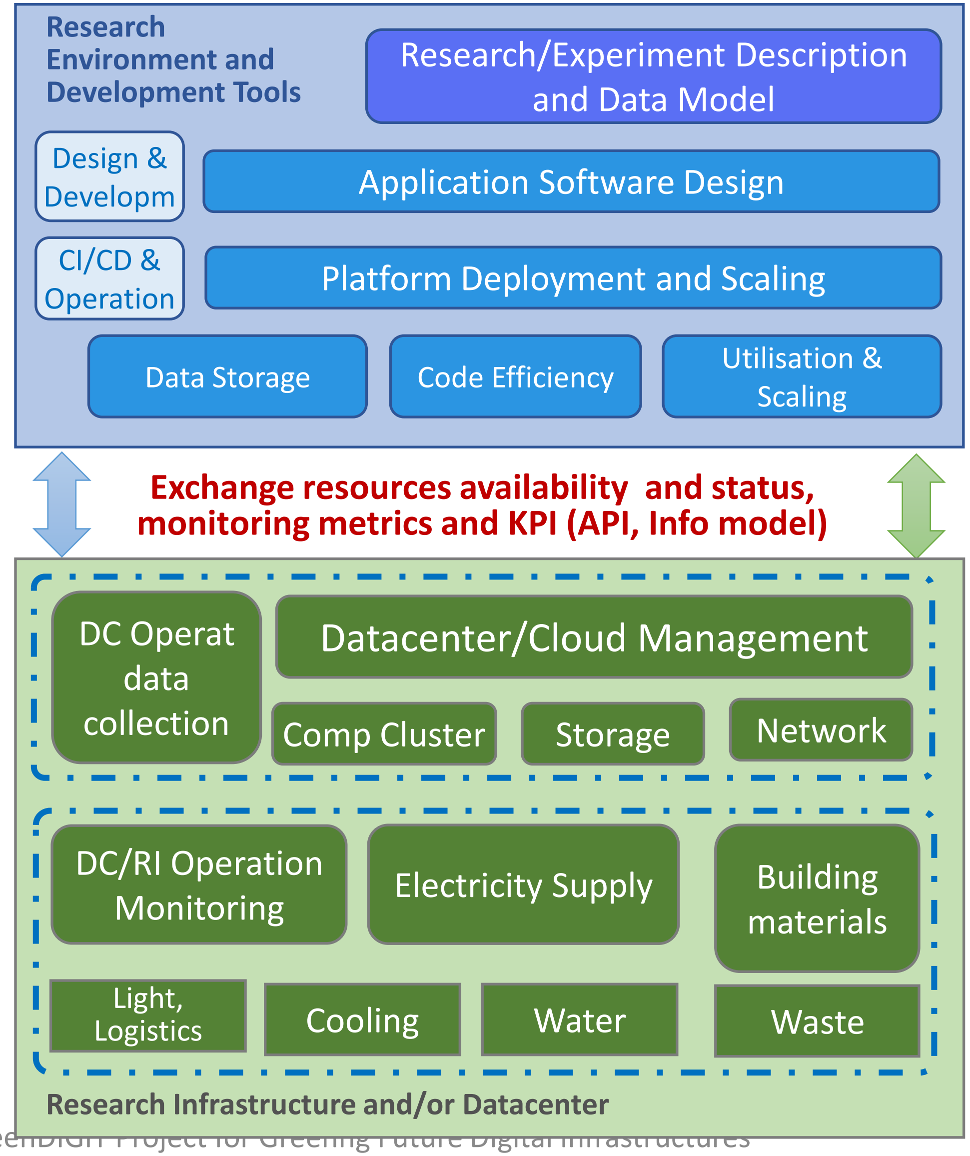
User group
- Project/Group user
- Researcher/ Scientific User
- Researcher/ Experimenter on RI or datacenter workflow

Shared Responsibility in Sustainability –
Moving to Environmental Sustainability by Design

GreenDIGIT

Users responsible for sustainability ***on*** the RI

Providers responsible for the sustainability ***of*** the RI



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Standards and regulations
Datacenter and RI Building and Operation

GreenDIGIT Project: Novel and Consolidating Approach
Shared Responsibility in Sustainability and Sustainability by Design

GreenDIGIT

Users responsible for sustainability ***on*** the RI

Researcher/ Project Responsibility:
Applications Development, Energy usage and KPI monitoring

Providers responsible for the sustainability ***of*** the RI

RI/Datacenter Provider/Operator Responsibility:
Monitoring Energy and environmental impact, metrics and KPI

Sustainability by Design Challenges

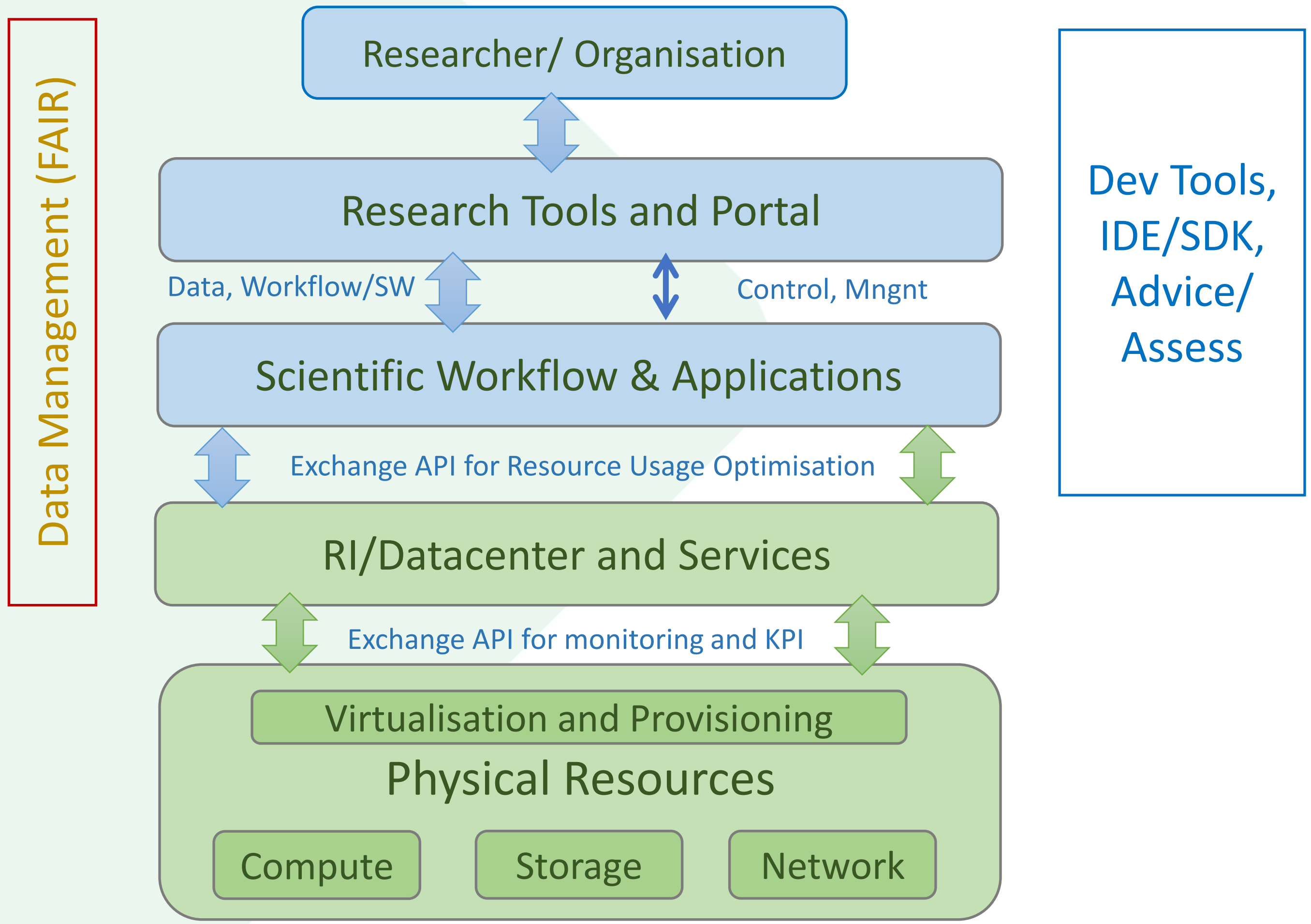
Architecture for Sustainability by Design
- Functional components, layers, API, Requirements
- Sustainability Architecture Design Principles (SADP)

Software and application components that can be optimised during design and controlled during operation
- Energy Efficient Software Design
- Green aware API including necessary energy, performance, environment information

(!) Common information/data model and metadata (naming)
- Including Requirements, KPI, Metrics
- Metrics and Metadata Registry
- Federated monitoring infrastructure
- Create a basis for research reproducibility
  - + FAIR for Sustainability

RI and applications lifecycle
- RI lifecycle stages (concept, design, development, deployment, operation, termination) and scientific workflow and research data

RI Sustainability by Design Components/Aspects: Motivated by the Shared Responsibility Model

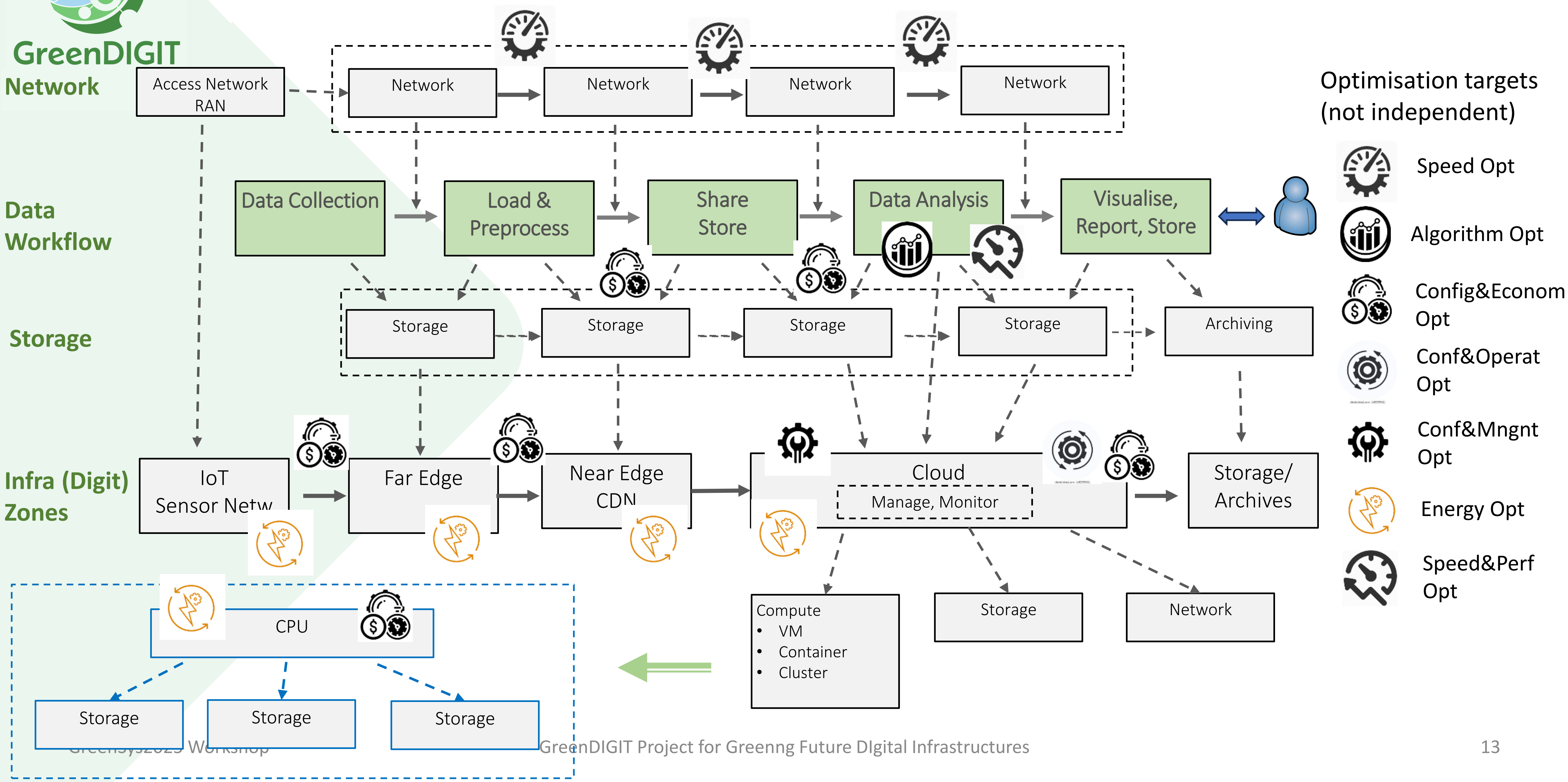


- **Architecture for Sustainability by Design**
  - Functional components, layers, API, Requirements
- **Software and application components that can be optimised during design and controlled during operation**
  - Green aware API including necessary energy, performance, environment information
- **(!) Common information/data model and metadata (naming)**
  - Including **Requirements, KPI, Metrics**
  - + FAIR for Sustainability
- **RI and applications lifecycle**
  - RI lifecycle stages (concept, design, development, deployment, operation, decommissioning) and scientific workflow and research data
- **Data Management and Optimised Storage**

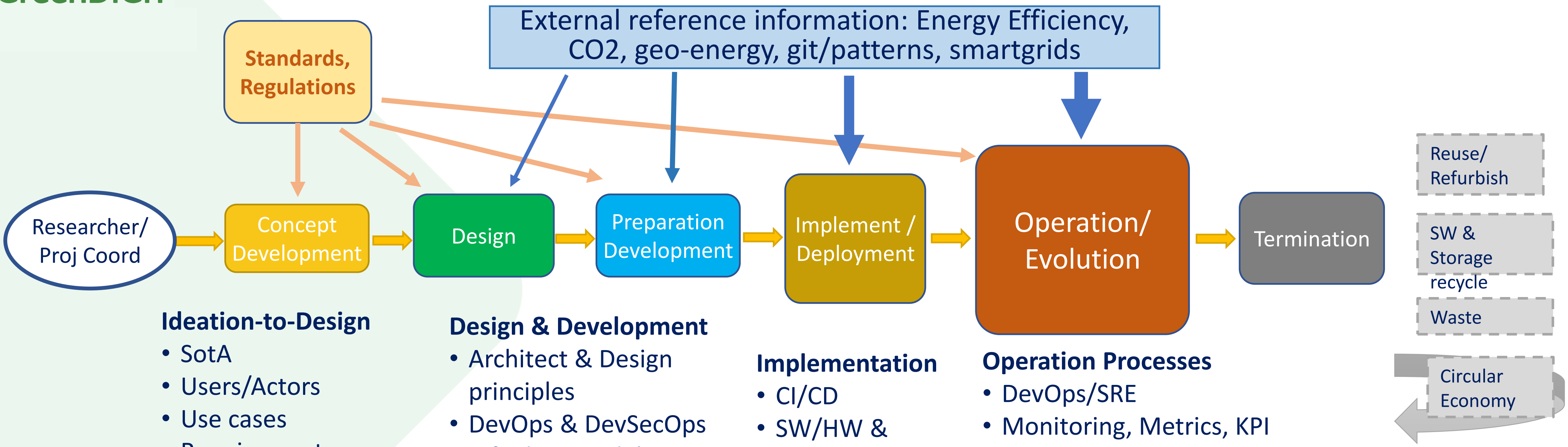
RI/Systems Sustainability by Design Components/Aspects

- Architecture for Sustainability by Design
  - Functional components, layers, API, Requirements **<= Sustainable Architecture Design Principles (SADP)** + Energy efficiency tactics (VU)
  - **RI continuum: (Research Object) – Sensor - (RAN) – Edge – Cloud – Workflow - Researcher**
- Software and application components that can be optimised during design and controlled during operation
  - Corresponding optimisation model to be proposed
  - Supported with VRE and IDE with sustainability awareness
  - Sustainability design patterns (software, application, middleware, infrastructure) **<= Architecture styles**
- Link and interaction between components via APIs
  - **Green aware API** including necessary energy, performance, environment information
  - Based on well defined Information Model
- Common information/data model and metadata (naming)
  - Including Requirements, KPI, Metrics
  - Verified with existing standards
  - Compliant with PUE and other KPI
- Relations between the system/RI and software sustainability aspects to be defined
  - System related aspects: Lifecycle, Operation and Governance, metrics on energy and GHG
- RI and applications lifecycle
  - Scientific workflow and research data lifecycle to be aligned with sustainability policy and monitoring

Multi-factor model for Energy Efficiency and Performance Optimisation



GreenDIGIT: RI Lifecycle Model: Stages, Activities and Factors



Ideation-to-Design
- SotA
- Users/Actors
- Use cases
- Requirements Engineering
- Architecture
- Standards/Regulations

Design & Development
- Architect & Design principles
- DevOps & DevSecOps
- Info data model
- Git, patterns, metrics, schemas, Repository
- API/WebAPI
- Testing, Logbook
- Project Management
- Tech Documentation
- Report, Compliance

Implementation
- CI/CD
- SW/HW & Implement Platform/Cloud
- Feedback

Operation Processes
- DevOps/SRE
- Monitoring, Metrics, KPI
- Maintenance
- Audit, Certification
- Electricity, Water, Buildings

Research Infrastructure Lifecycle
- All stages and processes to be in compliance with standards and regulations
- Shared Responsibility model and User /operator tools
- Continuous monitoring

RI Lifecycle Model: Stages, Actors, 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, Project Management • Info data model, API/WebAPI • Git, patterns, metrics, schemas, Repository, Testing, Logbook • 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
Operation	RI Management (including staffing and financial aspects) Operation team (Potentially, sustainability officer)	**Operation Processes** • Monitoring, Metrics, KPI, DevOps/SRE • 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

ESFRI Research Infrastructure Lifecycle Model and Requirements

- RILM stages – Compliant with ESFRI Lifecycle stages
- Reporting on Energy Efficiency and Environmental Sustainability
  - ESRS/CSRD and ESFRI RM2026
- Link to standards and regulations – Digital RI related
  - ESFRI Roadmap 2026 – To be analysed due to ESRS reporting specifics on Groups **E1 - Climate**, E2 - Pollution, **E3 – Water** and marine resources, E4 – Biodiversity and ecosystems, **E5 – Resource use and circular economy**
  - E1 group compliance:
    - E1-1, E1-2, E1-3 – Climate mitigation target, policies, actions; E1-4 - targets; E1-5 – Energy consumption and mix; E1-6 – Total GHG emission; E1-9 – Potential financial effect of measures
  - Compliance with LCA
- Roles and activities

GreenDIGIT: European Policies and Regulations for Development and Compliance

European Strategy Forum on Research Infrastructure (EFRI) Roadmap 2026:

- Environmental Sustainability of the European/ESFRI Research Infrastructures
- Compliance with ESRS (European Sustainability Reporting Standard) compliant with EU CSRD (Corporate Sustainability Reproting Directive)
- Lifecycle Analysis (LCA)

European Code of Conduct for Data Centers

- JRC BCP Sections 2024 Best Practice Guidelines for the EU CoC on Data Centre Energy Efficiency
- Commission Delegated Regulation (EU) 2024/1364 of 14 March 2024 for Data centers

ISO/EN/ITU-T Standards Compliance – Basis for Certification and Audit

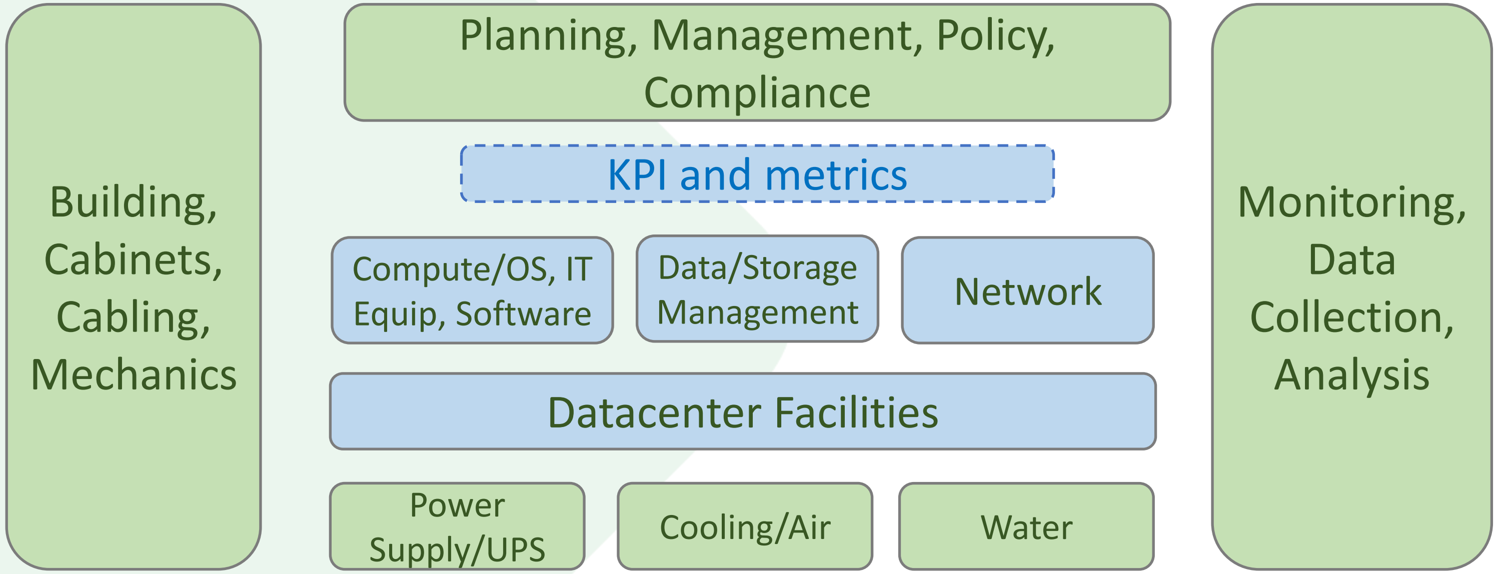
- ISO 50000, ISO 30134, ISO 14002
- EN 50600-4-1 and EN 50600-4-2 Datacenter and supporting infrastructure

Policies and Regulations for Energy Efficiency and Environmental Sustainability (GreenDIGIT Milestone Report MS4/MS8.1 – 50 pp.)

- Policies related to environmental sustainability and energy efficiency UN Sustainable development goals (SDG)
  - UN Digital Public Infrastructure for Environmental Sustainability
  - SBTi: The Science Based Targets Initiative
  - The European Green Deal
  - ESFRI Roadmap 2026 Public Guide
  - Climate Neutral Data Centre Pact (CNDCP)
- Regulations and Directive (to be checked)
  - JRC Data Center Code of Conduct
  - EU Delegated Regulation (EU) 2024/1364 of 14 March 2024
  - Corporate Sustainability Reporting Directive (CSRD) and European Sustainability Reporting Standards (ESRS)
  - Ecodesign for Sustainable Products Regulation (ESPR)
  - Energy Efficiency Directive (EED)
  - Waste Electrical and Electronic Equipment (WEEE) Directive
  - Lifecycle Analysis (LCA)
  - Environmental Management Standards (EMS)
    - Energy Management Systems ISO 50001, ISO 50002, ISO 14001, ISO 30134
    - European standards series EN 50600: EN 50600-4-1 and EN 50600-4-2 Datacenter and supporting infrastructure

Best Practice for the EU CoC on Data Centre Energy Efficiency: Main Infrastructure components – **RI/Datacenter Operator Perspective**

Also supported in the EC Delegated Regulation (EU) 2024/1364 of 14 March 2024



Areas of responsibility/ management

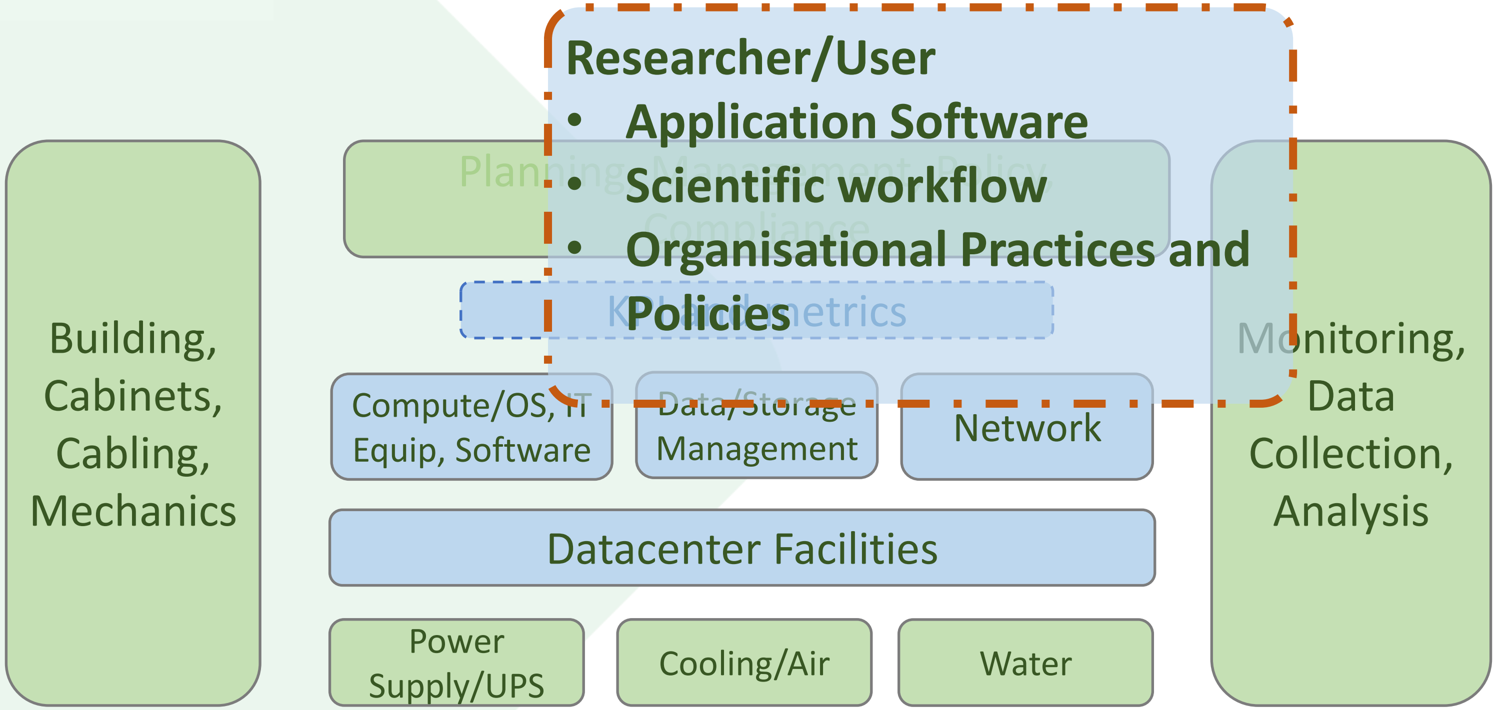
- Physical building
- Mechanical and electrical plant
- Data floor and air floor
- Cabinets and cabinets airflow
- Metrics and operation measurement points (?)
- **IT equipment**
- **Operating systems and virtualisation**
- **Software**
- Business Practices

Different roles of participants/ stakeholders

- Operator
- Colocation provider
- Colocation customer
- Managed services provider
- Managed services provider in colocation space

[ref] https://e3p.jrc.ec.europa.eu/sites/default/files/documents/publications/jrc136986_2024_best_practice_guidelines.pdf

Best Practice for the EU CoC on Data Centre Energy Efficiency – **Researcher/User Perspective**



Areas of responsibility/ management

- Research Development Environment
  - Application Software
  - Scientific workflow
- Control/Management RI/datacenter platform
  - Applications/SW lifecycle
  - IT equipment operation/ control and Optimisation
  - Operating systems and virtualisation
- Organisational Practices and Policies

Different roles of participants

- Managed services provider
- Research organisation, project
- Researcher (scientific workflow, data collection, scheduling)

Also supported in the EC Delegated Regulation (EU) 2024/1364 of 14 March 2024

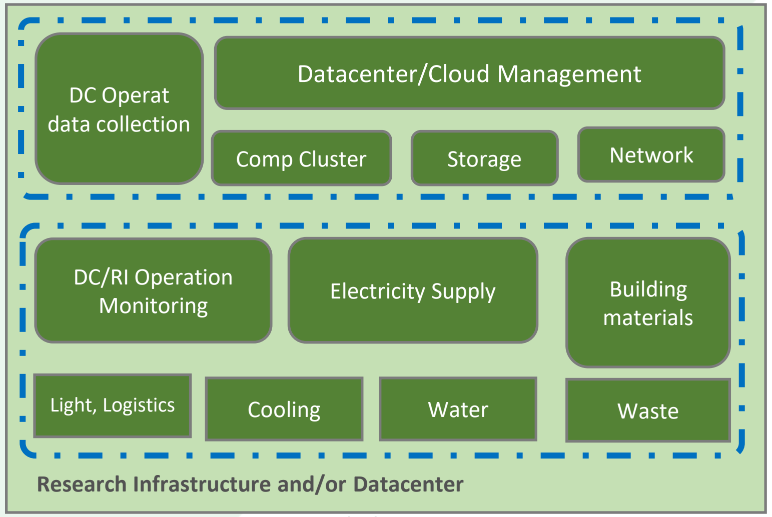
Linking KPI, Metrics and Design Patterns – To be clarified and extended for all Roles/Stakeholders

KPI (Key Performance Indicators)

- Energy consumption (kWh).
- PUE (Power Usage Effectiveness): Ratio total energy used to energy consumed by IT
- Carbon footprint GHG): Amount of CO_2 emissions associated with energy usage.
- Uptime or reliability: How well the infrastructure maintains consistent service
- Resource utilization efficiency: Resources (servers, storage, etc.) usage w/o wasting energy.

Metrics

- CPU usage and load: The utilization of computing resources.
- Energy draw per server.
- IT equipment energy consumption
- Temperature: The internal temperature of servers or cooling systems.
- Cooling system efficiency
- Carbon Emission/Equivalent (embedded GHG)



Design Solutions/Patterns

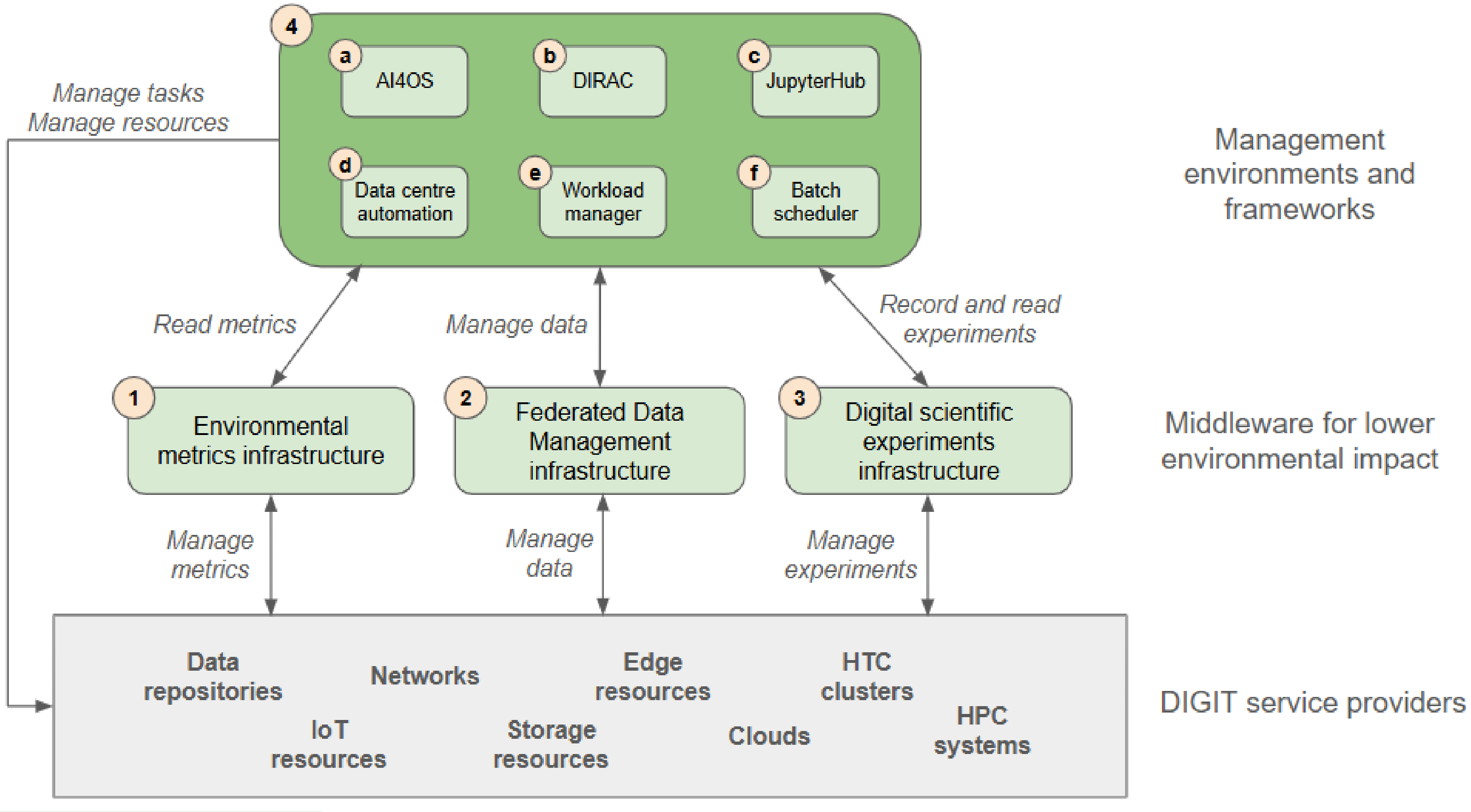
Under RI provider control/management

- Energy-efficient hardware
- Green energy sources.
- Monitoring and energy efficiency analytics and optimisation at the level of RI provider
- Advanced cooling systems
- Smart grid integration

Under user/developer control

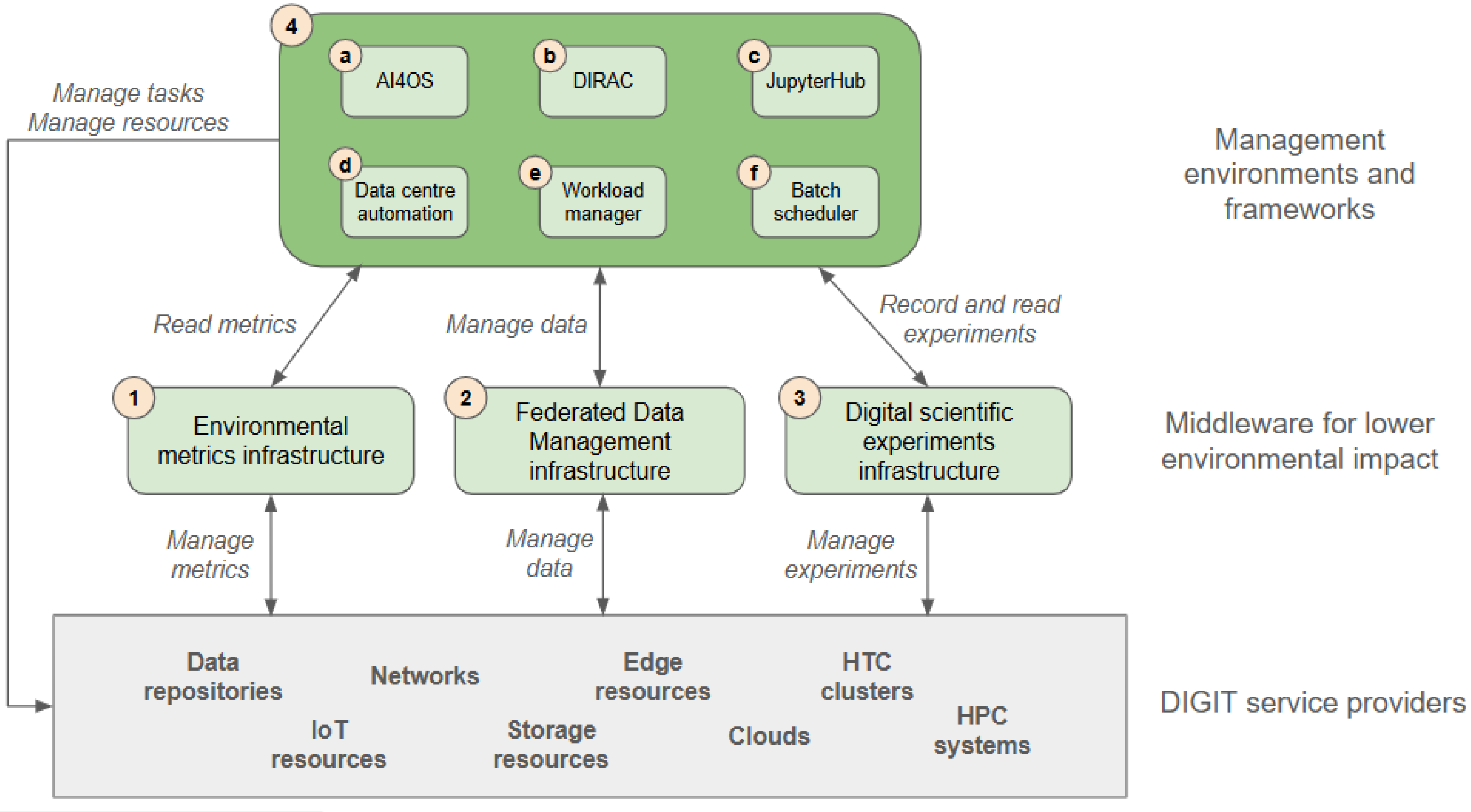
- Energy and environment aware applications development
- Modelling, simulation and testing as part of the development process
- Green software practices and templates
- Virtualization and containerization

GreenDIGIT Software Solutions for Environmental Impact Monitoring – Service Groups (1)



1. **Metrics collection infrastructure** to support RIs in the collection, aggregation and analysis of environmental impact-related metrics
2. **Federated data management infrastructure** to support RIs in the optimal use of their storage and network equipment by optimising data transfer, data replication and within federated environments
3. **Experimental research reproducibility infrastructure** to support RIs in the registration, lookup and replay of previously conducted digital experiments
4. **Environments and frameworks that provide integrated support** for users to the lowering of the environmental footprint of their activities on digital RIs. Goal:
   - Making informed decisions for resource allocation using data from the metrics infrastructure (area 1);
   - Minimising data transfers and storage with the use of the federated data infrastructure (area 2);
   - Offering scientific reproducibility with minimised computational impact (area 3).

GreenDIGIT Software Solutions for Environmental Impact Monitoring – Extension to existing Services (2)



- Monitoring infrastructure tools and frameworks as extension to GreenDIGIT RI/EGI services
  - An extension to the **AI4OS AI platform** that can optimise the execution of AI model training and inference tasks on federated cloud-HPC infrastructures: (a), (b) , (c), (d), (f)
  - An extension to the **DIRAC middleware** that can run massively parallel applications on federated High Throughput Cluster resources.
  - A **JupyterHub environment** that integrates with the rest of the ecosystem and can serve as a front-end towards users and user communities to perform computational analysis on digital RI services, with minimal impact on the environmental.
  - A **data centre automation service** that monitors the use of computers, the trend of incoming user requests
  - **Workload manager (resource broker)** that can choose the most suitable type of HW resources based on job characteristics inside one compute centre or among multiple centers, considering the environmental impact and expected time of completion of compute tasks.
  - **Batch scheduler** that can delay the execution of jobs to periods when the energy used by the centre is lower in carbon content, making the best compromise between time of completion and environmental impact.

Discussion: Greening Digital RI

- Environmental sustainability in the ESFRI Roadmap 2026
- Cooperation with/between digital RIs
  - GreenDIGIT cooperating partners: SLICES, SoBigData, EBRAINS, and EGI
- Possible topics for discussion with a technical focus
  - T1 - Sustainability landscape
  - T3 - Shared Responsibility in Environmental Sustainability
  - T4 - Energy efficiency on/of Research Infrastructure/Research Environment
  - T2 - Environmental Sustainability and emerging GenAI/LLM powered science

T1 - Sustainability landscape

- Sustainability is overloaded term
- Many economy and social domains claim to do sustainability, mostly focusing on sustainable/continuous activity and durable solutions
- Questions
  - What are the most active sustainability domains in your view?
  - How are they connected?
  - How to unite/merge/converge sustainability activity/development in different domains?
  - What are different actors and interests?
  - What community, projects, governmental and research bodies can do?

T2 - Environmental Sustainability and emerging GenAI/LLM powered science

- Expected growing use and benefits from powering science with GenAI and LLM for discovery and Data Science/ML for scientific data processing
- Required huge amount of energy for GenAI/LLM and ML is rising concerns about environmental sustainability and impact
- Questions
  - How is this problem perceived by the research community? Risk or sacrifice environment protection? What can be controlled by researchers?
  - Regulation/limitation vs training and thoughtful environment aware use?
  - What technical solutions can be researched or proposed for sustainable GenAI infrastructure?

T3 - Shared Responsibility in Environmental Sustainability

- Shared responsibility model is known in many domains.
- GreenDIGIT is proposing the Shared Responsibility Model for greening the whole RI ecosystem that describes responsibility of different stakeholders on different physical, software and operational elements of RIs
- Researchers/user and providers and operators are defined
- Questions
  - What are responsibilities? What are other stakeholders?
  - What information needs to be exchanged between stakeholders and functional RI components/services to facilitate decision on sustainability?
  - Sustainability aware tools for scientific workflow management? What are their expected functionalities?

T4 - Energy efficiency on/of Research Infrastructure/Research Environment

- Energy efficiency and environment impact monitoring and management is important area that is defined by numerous standards and regulations
- It is also a required reporting according many national programs and regulations
- Questions
  - What are existing/known to audience practices?
  - How to monitor and optimise energy efficiency and environmental impact of datacenters, RIs and research facilities?
  - What to measure and what is required metrics?
  - What are known methods and research regarding energy efficiency?

Supplementary information slides

- Sustainability landscape
- ESRS reporting required by ESFRI Roadmap 2026
- Discussion topics and questions
- Reference to relevant standards
- Other sustainability initiatives and sources

Landscape of the Sustainability Research, Development Policy - Goal to define GreenDIGIT place and contribution

General, not technical

- Economy and Financial sustainability
- Social and Community
- Cultural Sustainability
- Governance and Policy
- Sustainability in Supply Chain

Research, technology, circular operation

- Technology
- Manufacturing
- Environmental Research and Monitoring
- Research and Research Infrastructure/Facility
- Education and Competences

Place for GreenDIGIT

- Research domains
- Operation
- Education and competences

- In general, to promote the Shared Responsibility Model for Sustainability

ESFRI Roadmap 2026 Public Guide – Environmental aspects

- Page 25: The SWGs (Strategy Working Groups) evaluate the SCIENTIFIC CASE along six dimensions:
  - 1. scientific excellence
  - 2. pan-European relevance
  - 3. socio-economic impact
  - 4. user strategy and access policy
  - 5. e-needs & data
  - **6. environmental considerations**
- Page 28: With the Roadmap 2026, ESFRI will update the strategy on European RIs. It will cover:
  - **Environmental considerations**
- Page 37: ANNEX II: LIST OF MINIMAL KEY REQUIREMENTS FOR SCIENTIFIC CASE
- E-NEEDS & Data
  - **Environmental strategy** outlined at headline level (reference: applicable elements used in the European Sustainability Reporting Standards (**ESRS nomenclature**) – part of ESG (environmental, social, and governance) topics
- FINANCIAL
  - Long-term financial plan and budget also for **environmental strategy actions** (including outlined estimations for national nodes and an estimation of decommissioning costs if relevant

ESRS: Environmental standards

- ESRS E1: Climate change
  - This is the key environmental standard that will apply to most companies. The standard relates to climate change adaptation and mitigation, a company’s energy consumption, and risks and opportunities related to climate change. ESRS E1 includes the most mandatory disclosures of the 10 topical standards.
- ESRS E2: Pollution
  - Companies must report on issues including microplastics and any pollution of air, water, soil, or food resources.
- ESRS E3: Water and marine resources
  - This standard relates to a company’s water consumption, withdrawal, and discharges, as well as the extraction and use of other marine resources.
- ESRS E4: Biodiversity and ecosystems
  - Companies must consider their impact on biodiversity loss, the state of species, and the extent and condition of ecosystems.
- ESRS E5: Resource use and circular economy
  - Resource inflows, outflows relating to products or services, and waste are included under this standard.

Why Architecture is Important? -> Architecture design thinking

- Long term vision and coordination of cooperating teams
- Blueprint for designing, building, and maintaining the complex and interconnected systems that underpin research infrastructure
- Architecture design thinking – What does it mean?
  - To be cultivated starting from the university education
  - Provided as a professional training

Employing System and Design thinking for the structured design and development of complex computer/IT services and applications

Architecture design thinking in system and software engineering

- 1. **Problem-Solving Orientation**: Deep understanding of the problem to be solved, considering both functional requirements (what the system is supposed to do) and non-functional requirements (qualities such as performance, scalability, reliability, and usability).
- 2. **Holistic View**: Holistic view of the system, considering all components and their interactions.
- 3. **Iterative and Incremental Development**: Iterative and incremental development processes.,
- 4. **Stakeholder Engagement**: Engaging with all stakeholders, including end-users, developers, business owners, and others.
- 5. **Design Principles and Patterns**: Leverage established design principles and patterns to guide decision-making.
- 6. **Trade-off Analysis**: Analise trade-offs, such as performance versus cost or functionality versus security.
- 7. **Sustainability and Evolution**: Consider the long-term sustainability and evolution of the system.

Training Topic Groups for Core Green Competences

- Green Competences for Environmental Sustainability and Suggested Tutorial Topics – GRIU
  - Primary target – Researchers
- Green Competences for Environmental Sustainability and Suggested Tutorial Topics - SSES
  - Primarily professional developers, to be linked to academic curricula
- Technical staff of RI operator on monitoring Environmental Sustainability (RIOS)

- General Environmental Sustainability Competences and Knowledge (Green and Environmental Sustainability Awareness - GESA)
  - Targeting general public and users
- Tutorials and executive briefings for the RI management roles (MEB)

Green Competences for Environmental Sustainability and Suggested Tutorial Topics - GRIU

- General researchers (RI users) and experimental researchers on RI (GRIU)
  - 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/datacenter energy and environmental impact related metrics and KPI. Assessing and optimising energy consumption by the scientific workflow based on available energy related metrics and CO2/Carbon footprint (or embedded footprint) (60-90 minutes, with practical exercises)

Green Competences for Environmental Sustainability and Suggested Tutorial Topics - SSES

- Research application developers (Software and System Engineering for Sustainability - SSES)
  - LU-SSES01: RI/datacenter energy and environmental impact related metrics and KPI. Mapping between energy related metrics and CO2/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.

Green Competences for Environmental Sustainability and Suggested Tutorial Topics - RIOS

- Technical staff of RI operator on monitoring Environmental Sustainability (RIOS)
  - LU-RIOS01: Continuous datacenter/RI monitoring, managing monitoring tools and infrastructure, reporting.
  - LU-RIOS02: Workflow planning and optimisation on the datacenter 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.

Green Competences for Environmental Sustainability and Suggested Tutorial Topics – GESA & MEB

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

Sustainable/Durable Architecture Design Principles

General architecture design principles

- **Layered architecture design** for services and mechanisms
- **Multi-tier services and infrastructure design**, including combined multi-layer and multi-tier systems
- **Application Programming Interfaces (API)** for composable services

Service architecture related

- **Service Oriented Architecture (SOA)** and **Microservices Architecture (MSA)**
- **Cloud powered**, **cloud based** and **cloud native design principles** that require knowledge of the modern cloud architecture and cloud platform
- **Service lifecycle management** that includes services to support all lifecycle stages
- **Operations and management support**: SLA, monitoring, audit, certification compliance

Data management infrastructure and related services

- Data management services: service data, industrial or business data produced in operations; **FAIR data principles for data/metadata**.
- Big Data computation models and supporting platform
- Services and data management in the **continuum** of IoT/sensor networks, edge, cloud, data-driven applications

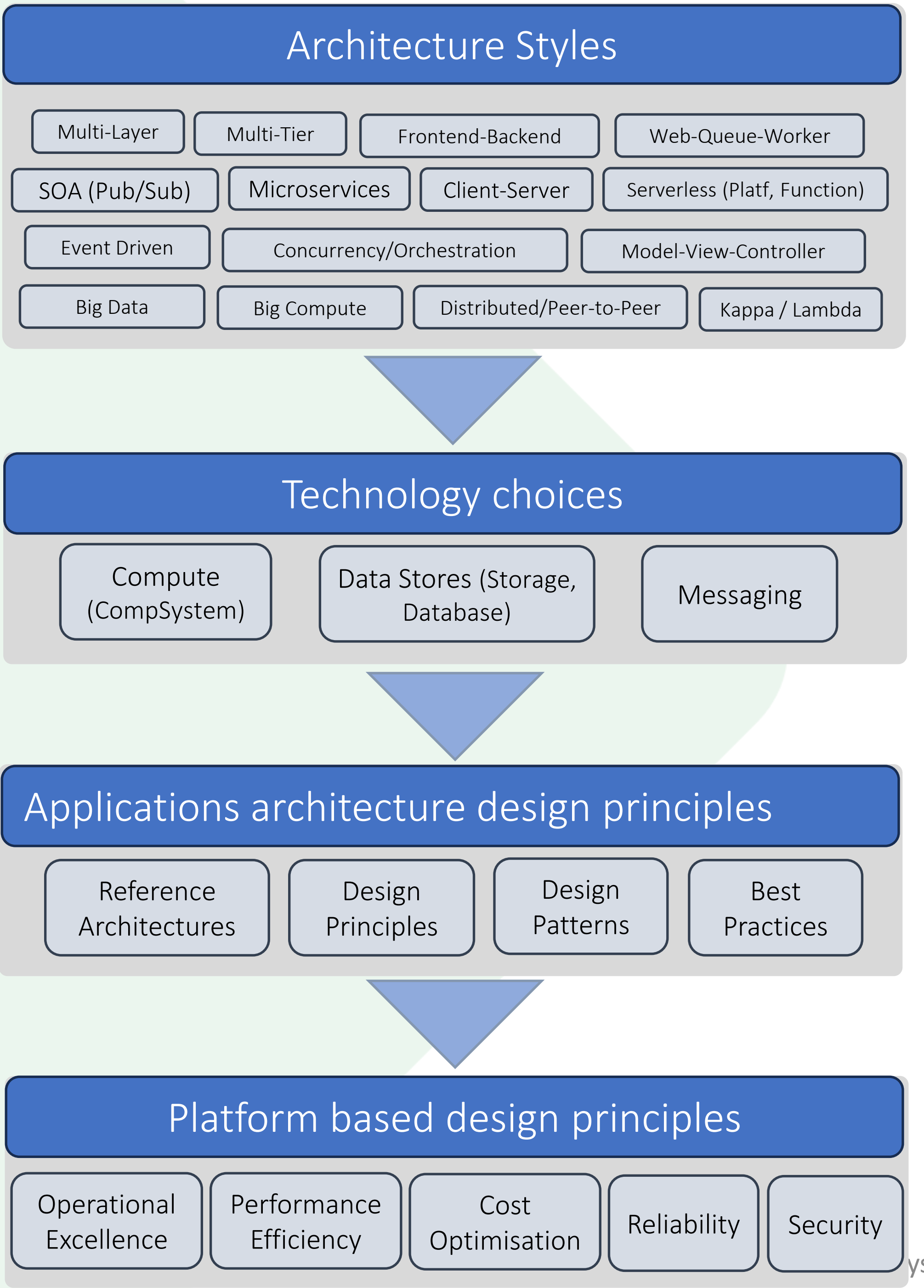
Security and compliance design principles

- **Security architecture and security services lifecycle management** including trust bootstrapping and secrets management; integration with the main infrastructure services via security API and policy definition.
- **Compliance frameworks** that define requirements and recommendations for services and infrastructure security design and operation
- **Industry best practices**: Federated AuthN, AuthZ, Identity Management

Project Management and DevOps based Agile principles

- **DevOps and SRE** (Site Reliability Engineering) practices applied to system and services engineering and operation.
- **DevSecOps** that addresses security design aspects during the whole system/services lifecycle, intending to address "Security by Design" concept
- General compliance with the **project management principles, models and procedures** applied to infrastructure, services, and data handling and analytics

Architecture Design Principles and System Design and Development



- Architecture Styles as necessary competence and knowledge foundation
  - Part of domain Body of Knowledge
- Technology choice
- Application/System design principles and design patterns
  - Software and Systems Engineering
- Platform based design principles and practices

D4.1 State of the Art – Analised technical areas: Datacenter, RI and Scientific Applications

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GreenDIGIT

D4.1 SotA: Chapter 7. Sustainable Software Design Practices for Scientific Software

- 7.1 Software Sustainability Recommendations by Green Software Foundation
- 7.2 The Software Carbon Intensity (SCI) Specification by Green Software Foundation
- **7.3 Sustainable Architecture Design Practices by Cloud Providers AWS and Microsoft Azure**
- 7.4 Software Energy Efficiency Tactics and Application to Scientific Software